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The Effects of Various Stern Configurations on the Directional Stability of Towed Barges

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17. Abstract

The purpose of this project was to study the directional stability of barges, designed for being pushed, when they are towed conventionally on a towline.

The test program consisted of the construction of a 1:15 scale model of a representative barge, accommodating three varying lengths of stern notch and three different designs of course stabilizing skegs.

Tests to determine the effects of variations in barge speed, barge trim and towline length, indicated that (1) large stern notches generate unstable flow vortices which can cause directional instability; (2) adequate directional stability can be provided by skegs with adjustable trailing edge flaps, or by a "Hydralift" type skeg; (3) directional stability is improved by increased stern trim and increased speed; and, (4) the effects of towline length on directional stability vary according to vessel speed.

The principle conclusion drawn from these tests is that stern configurations can be designed to provide minimal resistance for a barge being pushed by a tug in a stern notch as well as an adequate degree of directional stability when the barge is towed. Critical to success, however, is a clear knowledge of the flowline pattern at the stern in the vicinity of the notch/skegs, and proper positioning of the skegs therein.

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17. Résumé

Les travaux exposés dans le présent rapport visaient à déterminer la stabilité directionnelle en mode remorqué des barges du type à pousser.

Les essais ont été faits sur maquette 1/15 d'une barge de modèle courant, que l'on a dotée tout à tour de trois échancrures de profondeurs variables et de trois modèles différents de stabilisateurs.

Les essais visant à déterminer l'effet de différentes vitesses d'évolution, assiettes et longueurs de câble de remorquage ont permis de constater que: 1) les arrières à échancrure profonde engendrent des écoulements tourbillonnaires instables pouvant entraîner une instabilité directionnelle, 2) les stabilisateurs à volets de bord de fuite réglables et ceux de type Hydralift assurent une stabilité directionnelle acceptable; 3) la stabilité directionnelle s'améliore lorsque l'assiette de la barge est positive et que la vitesse augmente; et 4) l'influence de la longueur du câble de remorquage sur la stabilité directionnelle varie selon la vitesse d'évolution.

La conclusion principale tirée de ces essais est qu'il est possible de concevoir des configurations de barge à arrière échancré dont la résistance à la marche en mode poussé sera minimale et dont la stabilité directionnelle en mode remorqué sera quand même acceptable. Toutefois, pour réussir cette entreprise, il faut dissiper toute équivoque quant à l'allure des écoulements à proximité de l'échancrure et des stabilisateurs arrière, et déterminer l'orientation appropriée à donner aux stabilisateurs par rapport à ces derniers.

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Barge, stabilité directionnelle, arrière échancré, stabilisateurs, mode remorqué.	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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4039 Violet Street
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PREFACE

The subject of directional stability of towed barges is one which has received considerable attention over the past two or three decades, as operators strive to improve the economics of their towing operations by reducing resistance of the barge while still providing the requisite amount of directional control. Similarly, considerable development has taken place in the field of "push-towing" which offers significant improvements in both control and operational economics over a simple towed system.

The complication with push-towing is the mechanical complexity required to interconnect the tug and barge and the resultant "inflexibility" of interchanging tugs and tows.

In Canada there is a large and well developed fleet of tugs and barges, almost exclusively operating in simple towed systems. There are many areas of operation, particularly on the sheltered coastline of British Columbia, and the lakes and rivers of central Canada, where push-towing would be much more efficient.

Simple bridle connections can be used to secure a tug in a stern notch of a barge, where normal operations would be in limited sea states (up to sea state 3 or 4). The barge would be towed in conditions more severe than this. To maximize the benefits of push-towing in this way, a barge must have a "control device" which can offer the best possible combination of directional stability when towed, and minimum resistance when pushed.

This report addresses the above requirement, developed largely from the experiences of the author with a petroleum products barge, "Chevron Haida", built in 1981 to service the British Columbia coast. This barge has a notch designed for pushing with a simple bridle connection to a tug, and skegs with an adjustable trailing flap which could be set for either the "towed" or "pushed" mode. The success of these control surfaces was limited and erratic, and the barge behaviour was unpredictable.

The present study was therefore developed to examine the directional stability of barges designed primarily for push-towing, when operated in a towed mode, to determine the impact of notch size, and the effectiveness of a variety of skeg designs.

SUMMARY

This study deals with the stability of barges, designed for pushed operations, when, because of operational requirements, they have to be towed. Such requirements occur when high sea-states create dangerous relative motions in the notch nestling the tug bow in the stern of the barge. Although economics favour pushed operations (also called "push-towing"), operators have been reluctant to adopt this mode because of the operational limitation. If the towing of notched stern barges can be made stable, this limitation will disappear, allowing operators to benefit from the energy savings inherent in push-towing.

A test program was conducted to evaluate the effects on barge resistance and directional stability of a variety of sizes of stern notch in the barge, and of three different types of skegs used in conjunction with each of the various notches. Each combination of notch/skeg was tested over a range of typical barge towing speeds (6 - 10 knots), with varying trims of the barge and varying lengths of towline.

Tests were conducted on a 1:15 scale model of a typical west coast barge. Different skeg designs were provided by (a) the author, (b) Seatronics Technologies Ltd. - the "Hydralift" patented skeg, and (c) Total Naval Technological Associates Inc. (T.N.T.) - a steering flap type of active rudder.

The objective of the tests was to determine the following primary effects:

- The skeg configuration required to develop acceptable towed directional stability in the barge.

- The resistance of the barge system in each configuration.

Secondary objectives were to establish the effects on directional stability of:

- Towline length
- Barge trim

The results of the test program indicated the following:

- Skegs with adjustable trailing edge flaps could provide directional stability but at fairly high flap angles, resulting in high resistance. The alignment of the fixed leading edge portion with the flowlines is critical to generate the flow across the controlling flap surface.

- Skegs with adjustable trailing edge flaps produced the minimum resistance in a pushed mode.

- The fixed "Hydralift" skegs produced directional stability in the barge at an acceptable level of resistance augment, but the resistance augment is always present, whether towed or pushed.

- The configuration of T.N.T. skegs tested could not be made to provide directional stability in the barge. It is the author's opinion that the area of the control surfaces was insufficient for the size of barge.

- Barge directional stability with any skeg/notch configuration improves with stern trim.

- Barge directional stability with any skeg/notch configuration improves with increasing speed.

- The greater the depth of stern notch the greater the propensity for directional instability.

SOMMAIRE

Cette étude traite de la stabilité directionnelle des barges du type à pousser que les conditions de navigation obligent à exploiter en mode remorqué; notamment, en cas de mer forte où les mouvements relatifs de la proue du pousseur et de l'arrière de la barge atteignent une amplitude dangereuse. Bien que la recherche de la rentabilité favorise la solution des barges ou convois poussés, les armateurs ont toujours hésité à adopter ce mode à cause de ses limites opérationnelles. Or, si la stabilité des barges à arrière échancré, c'est-à-dire du type à pousser, pouvait être garantie en mode remorqué, les armateurs n'auraient plus à craindre les limitations opérationnelles précitées et pourraient tirer profit des avantages énergétiques découlant de l'utilisation d'ensemble barge-pousseur.

Dans cette optique, un programme d'essais a été conduit sur maquette 1/15 d'une barge de modèle courant sur la côte Ouest. Il s'agissait de déterminer la résistance à la marche et la stabilité directionnelle sous diverses configurations d'arrière échancré et avec trois types différents de stabilisateurs. Dans chaque cas, l'essai a été conduit à différentes vitesses types (entre 6 et 10 noeuds), sous diverses assiettes de barge et en variant la longueur du câble de remorquage.

Les stabilisateurs essayés ont été conçus par a) l'auteur du présent rapport, b) Seatronics Technologies Ltd. (stabilisateur breveté Hydralift) et c) Total Naval Technological Associates Inc. (gouvernail actif à volet "flettner" asservi).

L'objectif des essais était de déterminer principalement:

- le modèle de stabilisateur susceptible de conférer à la barge une stabilité directionnelle acceptable en mode remorqué
- la résistance à la marche propre à chacune des configurations testées.

Les objectifs secondaires étaient de déterminer les variations de la stabilité directionnelle selon:

- la longueur du câble de remorquage
- l'assiette de la barge.

Les résultats des essais ont été les suivants:

- Des stabilisateurs à volets réglables sur bord de fuite peuvent garantir une stabilité directionnelle adéquate mais seulement à des angles de braquage passablement élevés produisant ainsi une forte traînée. L'alignement correct de la partie fixe des stabilisateurs est critique car un mauvais alignement a pour effet de créer des décollements et de réduire l'efficacité des volets réglables.

- Ce sont les stabilisateurs à volets de bord de fuite réglables qui ont engendré la plus faible traînée en mode poussé.

- Les stabilisateurs fixes Hydralift ont contribué à la stabilité directionnelle au prix d'une augmentation de traînée acceptable qui est cependant présente même en mode poussé.

- Les stabilisateurs de TNT Inc. ont été inefficaces sous quelque configuration que ce soit. De l'avis de l'auteur, ce phénomène s'explique par une surface active des stabilisateurs trop petite au regard de la taille des barges à équiper.

- La stabilité directionnelle est améliorée en assiette positive, quelle que soit la configuration stabilisateur/arrière échancré considérée.

- La stabilité directionnelle s'améliore dans tous les cas à mesure que la vitesse augmente.

- Plus l'échancrure est profonde moins la stabilité directionnelle est bonne.

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1. INTRODUCTION

1.1 Background Information

Tugs and barges are a common form of marine transport for bulk commodities. One of the great advantages of this simple form of transportation is the flexibility offered by the ability to mix and match tugs to various tows, or to transfer tows from one tug to another, thereby maximizing the utilization of the expensive manned "propulsor" part of the system, and enabling the bulk "storage" part of the system to be used as a warehouse during a period of prolonged loading or unloading if necessary.

With increasing fuel and manning costs, operators have examined various means of improving the economics of this simple form of transportation. One of the most obvious methods has been to push the barge rather than tow it. By pushing, total system resistance can be reduced by up to 30 - 40 percent in some cases by eliminating towline resistance and the resistance caused by skegs or similar appendages fixed to the underwater stern of a barge for the purpose of providing directional stability to the tow.

The push-tow system has several limitations, however, which must be overcome to be a viable transportation system, the primary one of which is the relative motions of tug and barge in a sea state. Several patented systems have overcome this difficulty by complex and expensive mechanical connections which limit the number of degrees of freedom between the units to usually just one (typically pitch) and often none. The solving of the problem of relative motions in this manner, however, results in a significant loss of flexibility between units, and for a large fleet owner that may become self-defeating.

The solution for many operators therefore becomes to have a set of barges with simple notched sterns into which a tug can be connected by a simple bridle system so that the barge may be pushed when conditions of sea state permit and then have a conventional towing arrangement for the balance of operational time.

In 1981, the author's company was involved in the design of a refined petroleum products barge, the "Chevron Haida" (Figure 1) which featured a deep notch designed to accommodate a variety of tugs (although in fact it was intended to dedicate one tug to this service). To maximize the potential benefits of pushing this barge, and still be able to tow it safely, the barge was equipped with skegs with a hinged trailing edge flap. The flap had a designated "push" position in which it was aligned with the flow for minimum resistance, and a "tow" position in which the flap was angled outboard to provide directional stability to the barge when towed.

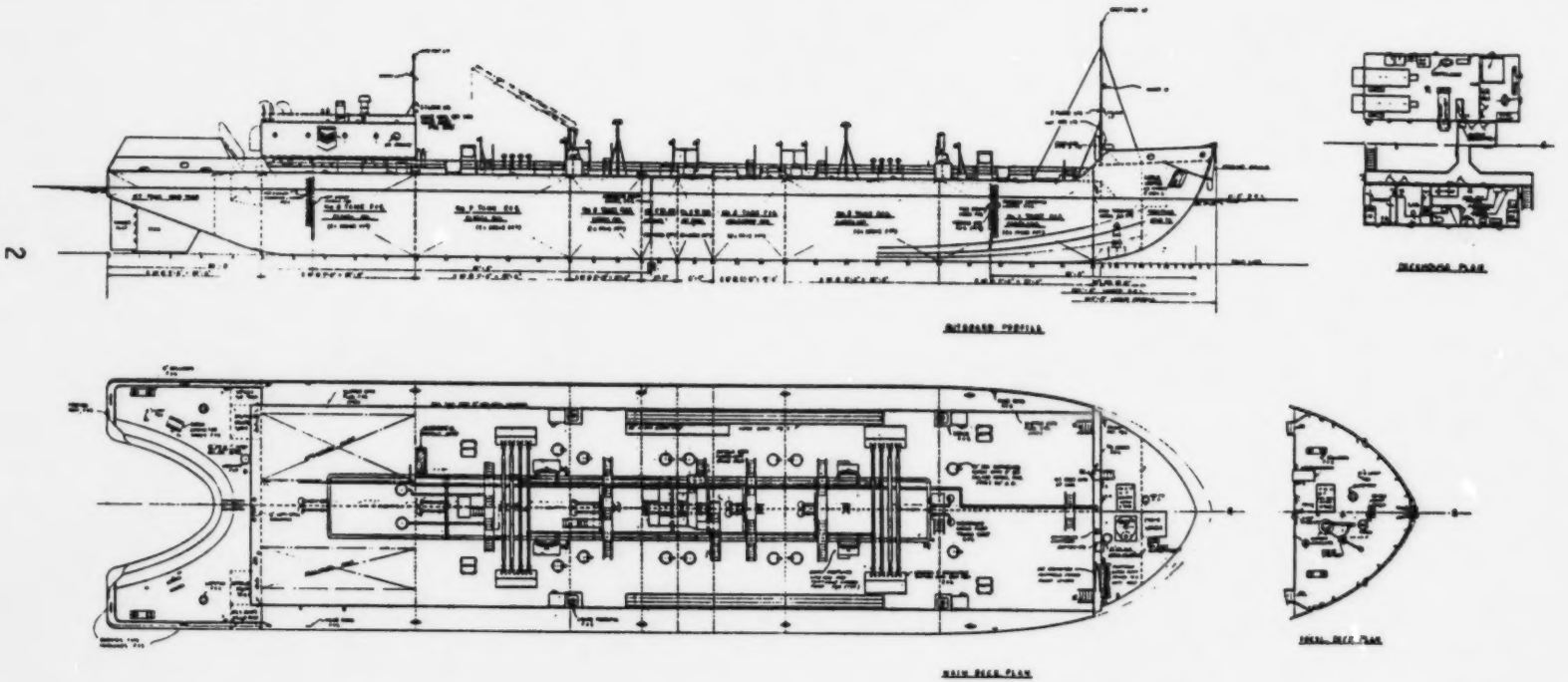

Figure 1 - "Chevron Haida"

In spite of a limited program of model testing of these skegs prior to construction, which showed suitable directional stability in towing, since entering service the performance of the "Chevron Haida" when towed has been erratic; sometimes stable, sometimes badly unstable.

From the efforts to solve the problems on that barge has grown the motivation for this study, namely to conduct a systematic series of tests to examine the effects on barge resistance and directional stability of stern notch size and skeg configuration, as first order variables, and of barge trim and towline length as second order variables.

In Canada, there are large fleets of tugs and barges that could benefit from the results of this research. If a simple, safe and reliable method of push-towing could be devised, many vessel operators would opt for this method where practical, saving potentially millions of dollars in fuel and labour (time) costs per year.

1.2 Barge Form Design

This report does not examine the effects of variations in barge hull form which might impact on the subject of directional stability. Over the course of the past three decades, the author's company has designed several hundred barges. Due to an extensive series of model testing for our own designs, and examination of other research and new buildings, for conventional bulk cargo barges the optimum basic form geometry is now well established. Our own design criteria for sea going barges are confirmed by the work of Brix[1], summarized as follows:

- Maximum angle of stern rake from horizontal equals 18 degrees
- Bow form - "spoon" or modified multi-chine "spoon" shape

1.3 Test Objectives

The basic objective of the test program was to fully research the phenomenon of course instability in barges with notched sterns, and moreover to define practical solutions to this problem.

Therefore the following precise test objectives were set and followed:

- Determine the effect of varying length (depth) of stern notch
- Examine the effectiveness of various types of stern skegs with the notched stern form
- Examine the effects of barge trim on directional stability
- Examine the effects of towline length on directional stability

All the above were to be examined over a speed range indicative of normal barge towing practice, and the resistance associated with each configuration measured.

---

(1) - Brix, Jochim E. Lighters and Seagoing Barges and the Design of Yaw Controlling Units, 2nd International Tug Conference organized by Ship & Boat International, 1972.

2. TEST PROGRAM

To determine the effects on barge performance as outlined in the introduction, an extensive program of model testing was conducted. The procedures and results are clearly defined in subsection 2.3 of this report.

It is useful, however, to first examine the criteria by which barge directional stability is determined.

2.1 Directional Stability

The subject of barge directional stability has been the topic of considerable research, and the paper by Brix[1] mentioned earlier is perhaps now considered the definitive work on the criteria for and evaluation of directional stability.

Brix defined a "damping factor", a measure of the ability to return to initial course after an offset or disturbance from that course.

The damping factor "D" is defined by Brix as follows:

$$\Delta = \ln \frac{\Psi_i}{\Psi_{i+i}} = 2\ln \frac{\Psi_i}{\Psi_{i+1/2}} = \frac{2\pi D}{\sqrt{1-D^2}}$$

where

D = damping factor

Δ = logarithmic decrement of a free damped oscillation

Ψ_i and

Ψ_{i+1} = amplitudes of one yawing cycle

Thus,

$$D = \sin\left[\arctan\left(\frac{\Delta}{2\pi}\right)\right]$$

or,

$$D = \sqrt{\frac{\Delta^2}{\Delta^2 + 4\pi^2}}$$

---

(1) - Brix, Jochim E. Lighters and Seagoing Barges and the Design of Yaw Controlling Units, 2nd International Tug Conference organized by Ship & Boat International, 1972.

Then damping factor "D" yields:

D = 0 - an undamped oscillation (Figure 2)
D = 1 - oscillation with optimum (i.e., maximum) damping (Figure 3)
$0 < D < 1$ - damped oscillation
$D < 0$ - increasing amplitude of oscillation (Figure 4) (i.e., negative damping)

The circular frequency $\sim$(1/sec) of a damped yawing oscillation is:

$$\sim = \frac{2\P}{T} = w\sqrt{1-D^2}$$

where

$\sim$(1/sec) = circular frequency of a damped oscillation
w (1/sec) = circular frequency of an undamped oscillation
T = period for one complete yaw cycle

The following quotation(1) summarizes the importance of both damping factor "D", and circular frequency "$\sim$" on barge performance:

> " Hence it follows that an optimum stabilising skeg has the following properties:
>
> 1. $D \to 1$ 2. $v \to 0$ (5)
>
> " If a damping factor $D \equiv 1$ is attained a yawing motion will be damped immediately, *i.e.*, the towed barge will return to straight course without any further oscillation. When the circular frequency tends to small values a smooth extinction will take place.
>
> " The period T (sec.) of a yawing motion is about T = 100 to 200 sec. for hopper barges, T = 300 to 400 sec. for seagoing barges of medium size and T = 600 to 700 sec. and more for large units.
>
> " A towed vessel has an individual characteristic circular frequency v (1/sec.) of the yawing motion, keeping hawser length, speed and displacement constant. It is only slightly influenced by modifications of the skeg system.
>
> " A remarkable increase of the circular frequency v, however, was observed in numerous model tests with:
>
> (a) the decrease of displacement;
> (b) the increase of towing speed;
> (c) the decrease of the hawser length."

We have, for purposes of the analysis in this study, used the above definitions of both damping factor and circular frequency.

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(1) - Brix, Jochim E. Lighters and Seagoing Barges and the Design of Yaw Controlling Units, 2nd International Tug Conference organized by Ship & Boat International, 1972.

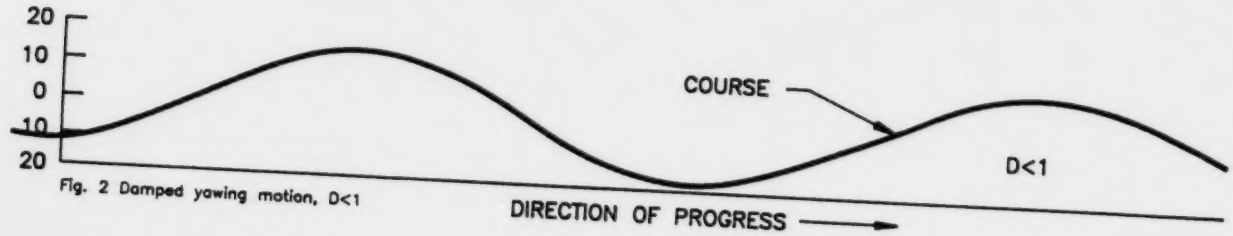


Fig. 2 Damped yawing motion, D<1

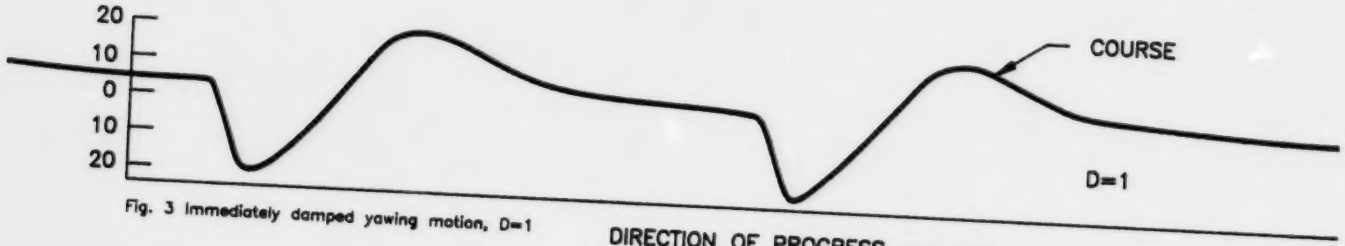


Fig. 3 Immediately damped yawing motion, D=1

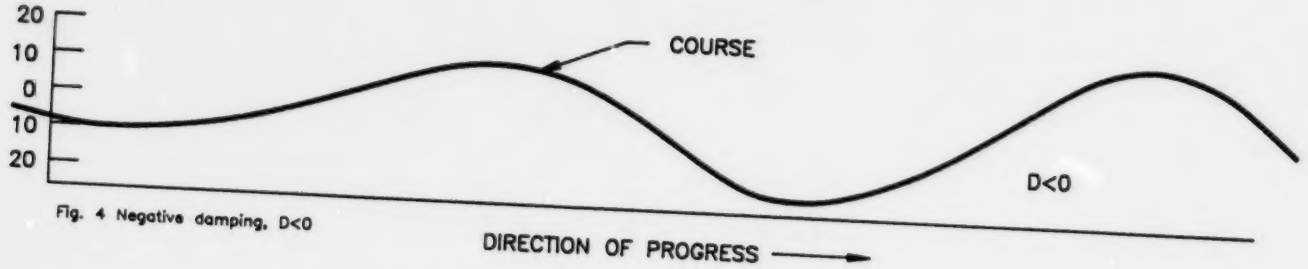


Fig. 4 Negative damping, D<0

2.2 Methods of Barge Stabilization

The inherent directional instability of barge forms is well recognized and has been the subject of considerable research since the early 1950's. To correct this phenomenon, a variety of methods are available. All the present methods, however, create directional stability by a combination of transverse hydrodynamic lift and increased drag.

The most common form of stabilizer is a fixed skeg of planar or curved surface (Figure 5). A variation on this theme is a skeg with an adjustable trailing edge flap (Figure 6). Recent developments have been patented devices such as the multiple, high aspect ratio foil, "Hydralift" skeg (Figure 7) and gyro-stabilized steering rudders such as developed by Total Naval Technological Associates Inc. (Figure 8).

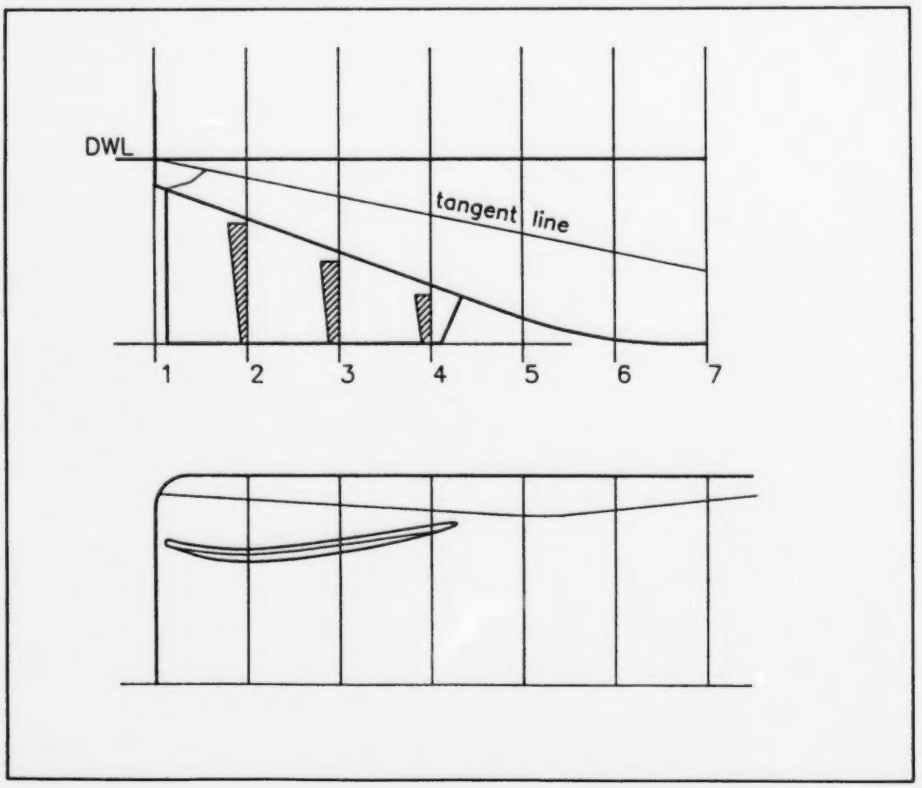


Figure 5 - Fixed Skeg

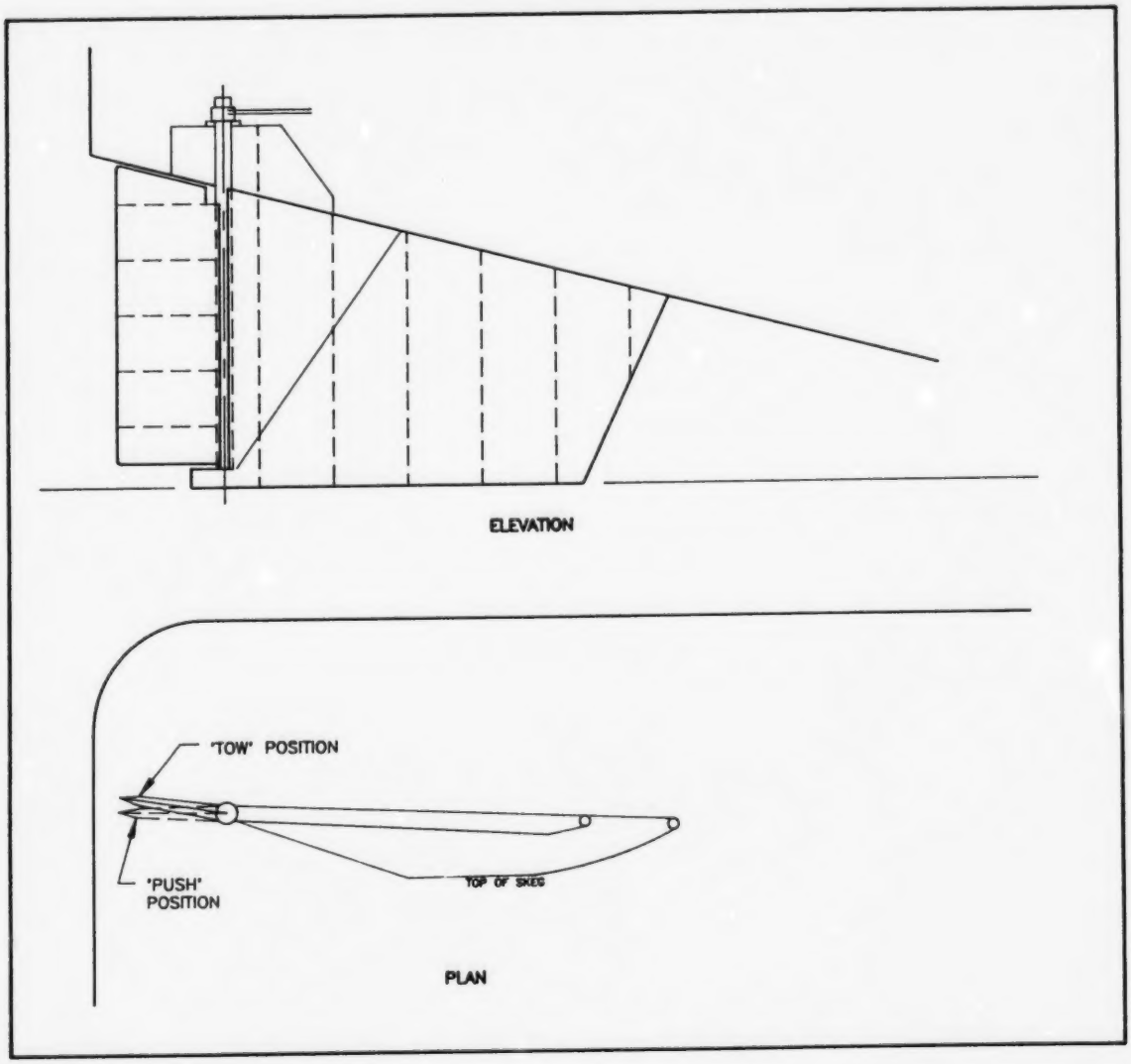
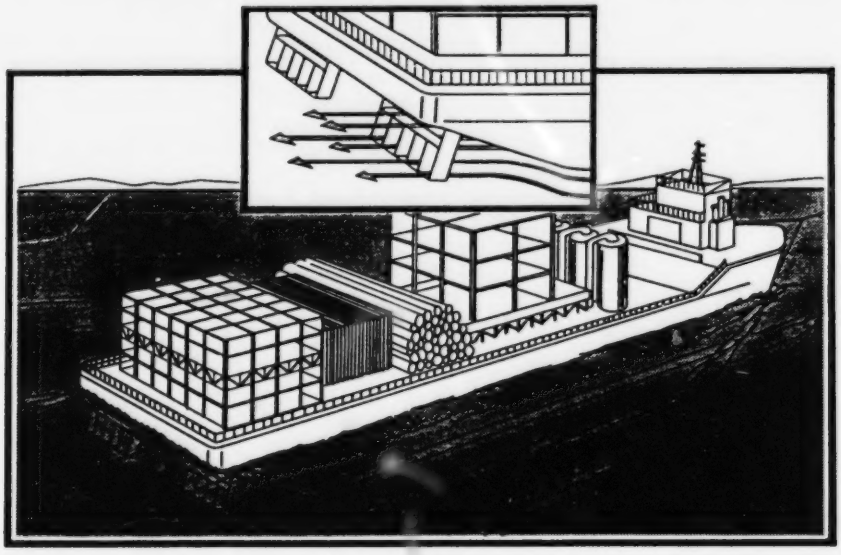


Figure 6 - Adjustable Flap Skeg

HYDRALIFT II®



Hydralift II, a new concept in barge skegs, is the only one that can reduce barge towing costs by 25% to 30% ... or increase towing speeds with no increase in horsepower.

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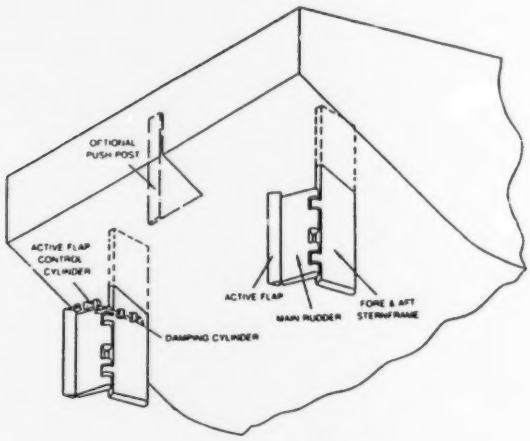
Figure 7

ACTIVE FLAP RUDDER
FOR
TOWED BARGE APPLICATION



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- 1 - 1.5 Knots Faster
  and
- Steering Capability
- Increased Safety
- Steering from Tow Boat by Radio Controls
- Alternative Automatic Towline Tracking
- One H.P. Steering Motor yields 5 TONS THRUST!
- Hard Over to Hard Over in 5 Seconds (if desired)

WE'RE STEERING A COURSE TO SUCCESS BY SAVING YOU MONEY!

TOTAL NAVAL TECHNOLOGY INC.

Figure 8

2.3 Model Test Procedures

2.3.1 General

To fulfill the objectives of this study as defined in 1.3, the following were to be examined:

- effects of varying notch depth, expressed as a fraction of the length of the aft rake of the barge,
- the flowlines in the stern region as influenced by the various notches,
- the effects of various skeg geometries in providing directional stability,
- the effects of varying towline length on directional stability,
- the effects of stern trim on directional stability,
- the resistance of each configuration over a range of speeds,
- the ability of a tug in the stern notch to exercise directional control over the barge in each of the varying configurations,

Offshore Research Ltd. of Vancouver were retained to construct a suitable scale model from a parent hull form designed by Robert Allan Ltd., to conduct the full matrix of tests and to analyze and graphically present the data collected.

2.3.2 Models

a. Hull. A parent hull model was built to a 1:15 scale with removable stern-notches. The lines plan is shown in Figure 9 with the notch arrangement.

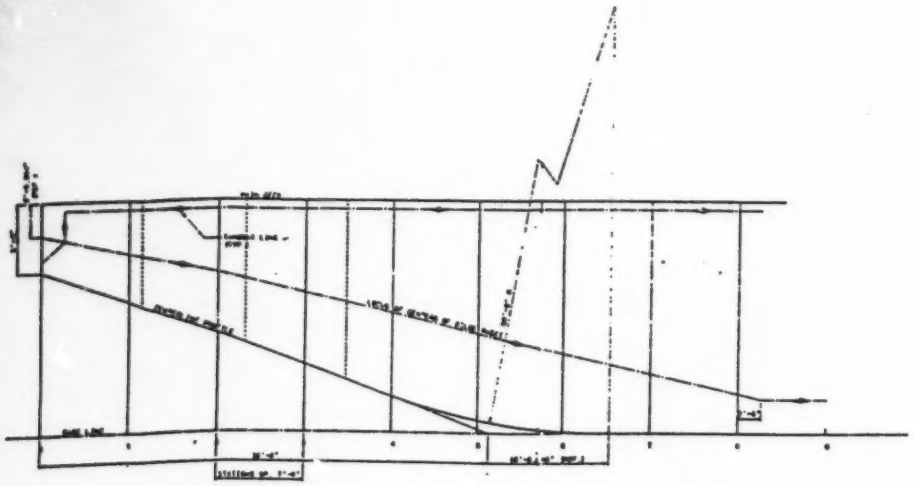
b. Skegs. Three skeg arrangements were manufactured to suit the parent hull in accordance with drawings supplied by their designers:

- Original. The typical fixed skeg with adjustable flap skeg was designed by Robert Allan Ltd. and is designated "original". The general arrangement drawing is reproduced as Figure 10.

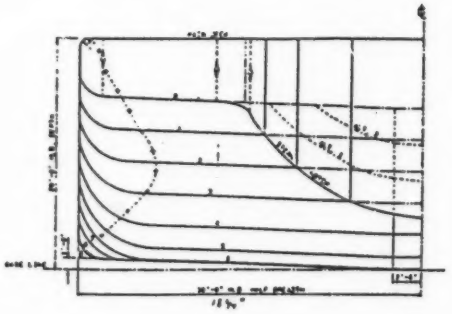
- Hydralift. The skegs proposed by Seatronics Technologies Ltd. are designed "Hydralift". The general arrangement drawing for the model is reproduced in Figure 11.

- T.N.T. The active skegs with trailing edge flap design proposed by Total Naval Technological Associates Inc. are designated "T.N.T.". The general arrangement drawing is reproduced in Figure 12.

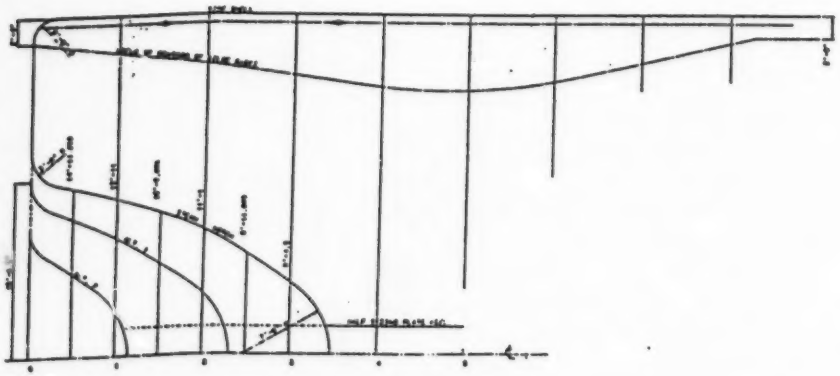
c. Tug. A representative existing tug model was manufactured from wood and fitted with twin propellers and rudders. A watertight plexiglass deck with access covers protected the equipment inside. Prior to tests, the model was ballasted to a representative waterline.



SHEER PLAN



BODY PLAN



HALF-BREADTH PLAN

Figure 9

ROBERT ALLAN LTD.
NAVAL ARCHITECTS MARINE ENGINEERS
600-1300 SUMMER ST. VANCOUVER B.C.

TRANSPORT CANADA

BARGE STERN NOTCH STUDY

AFT END LINES

1/4" = 1'-0"

APR. 16, 1985

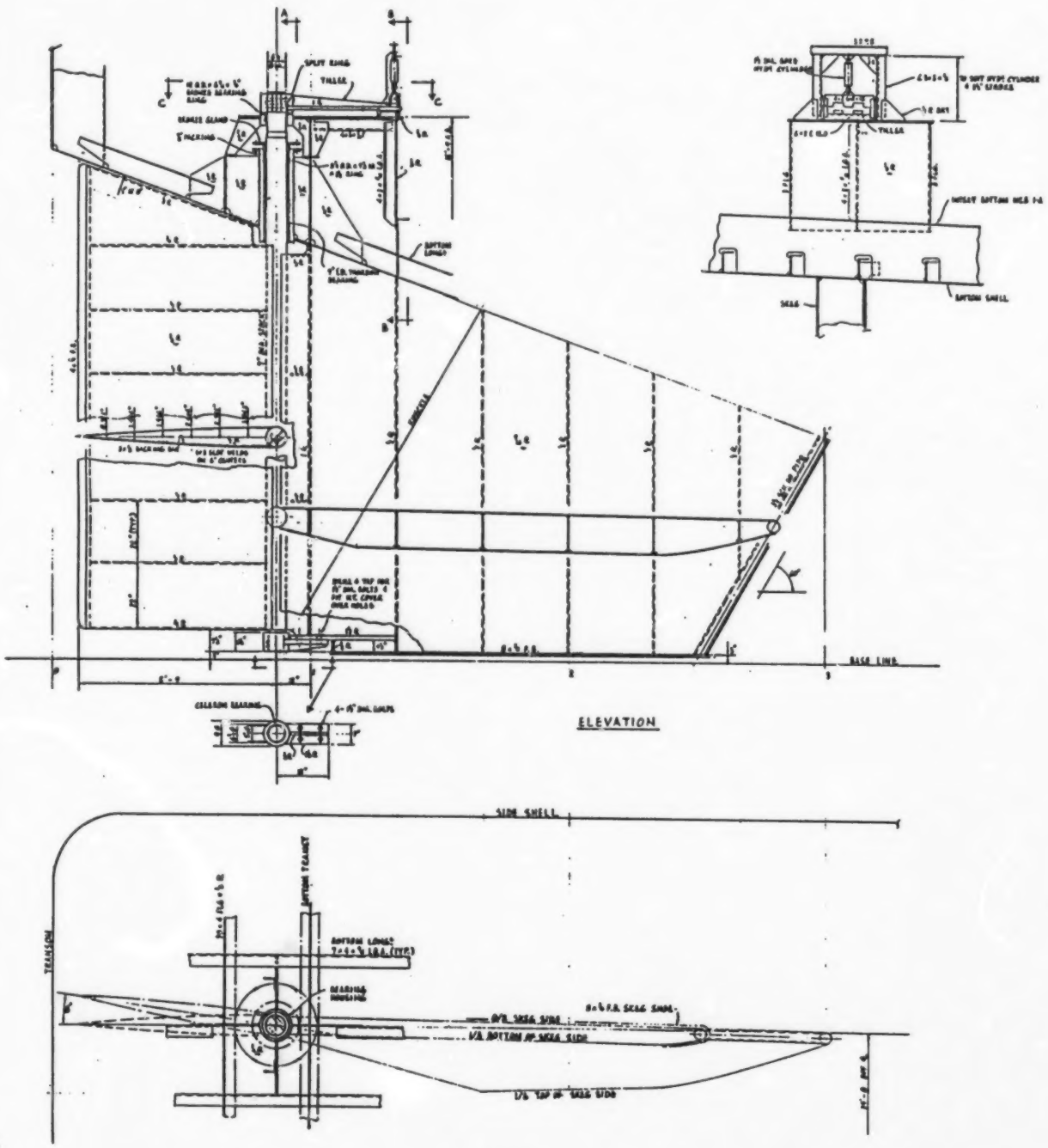


Figure 10

ROBERT ALLAN LTD.

ORIGINAL SKEGS

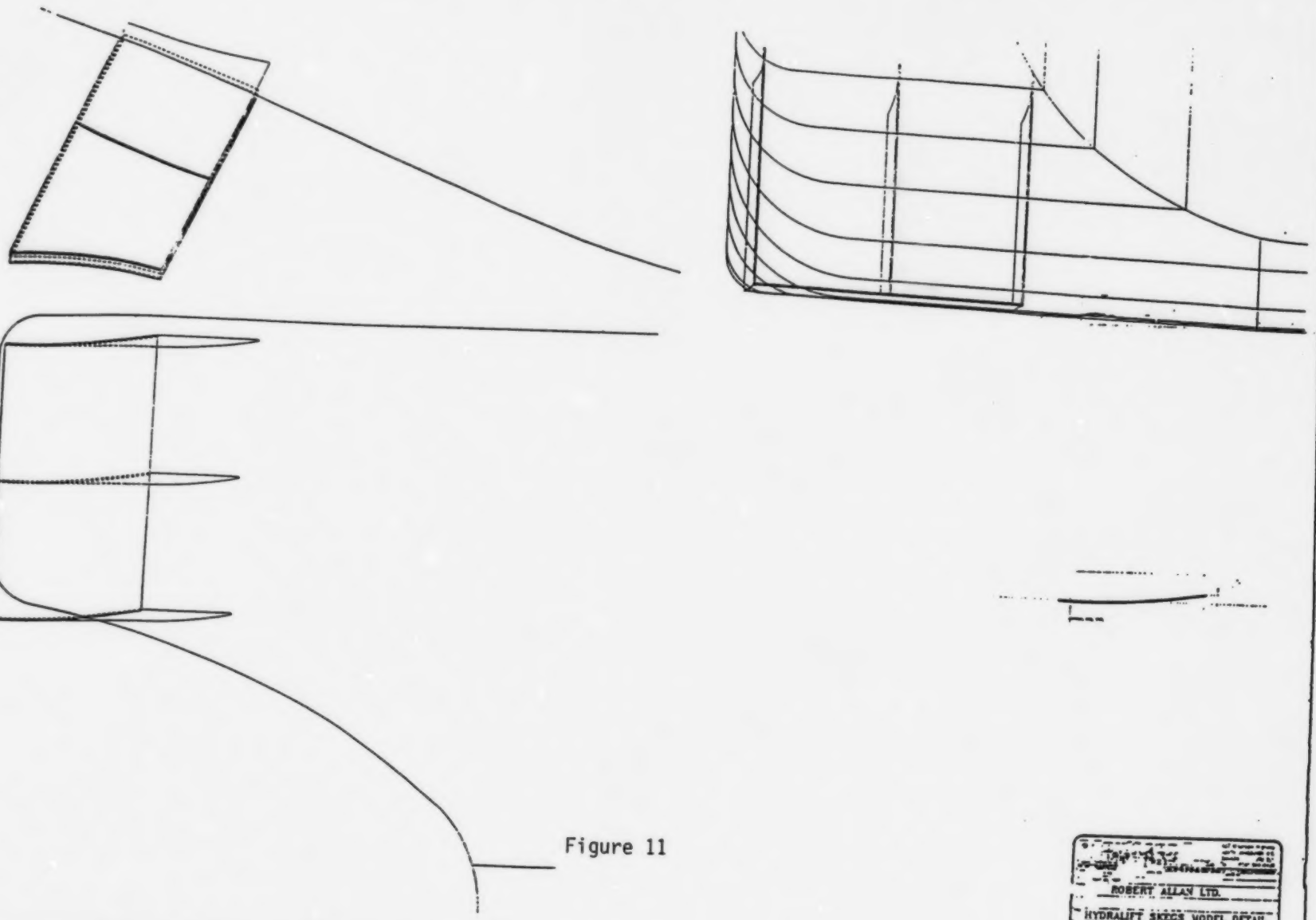


Figure 11

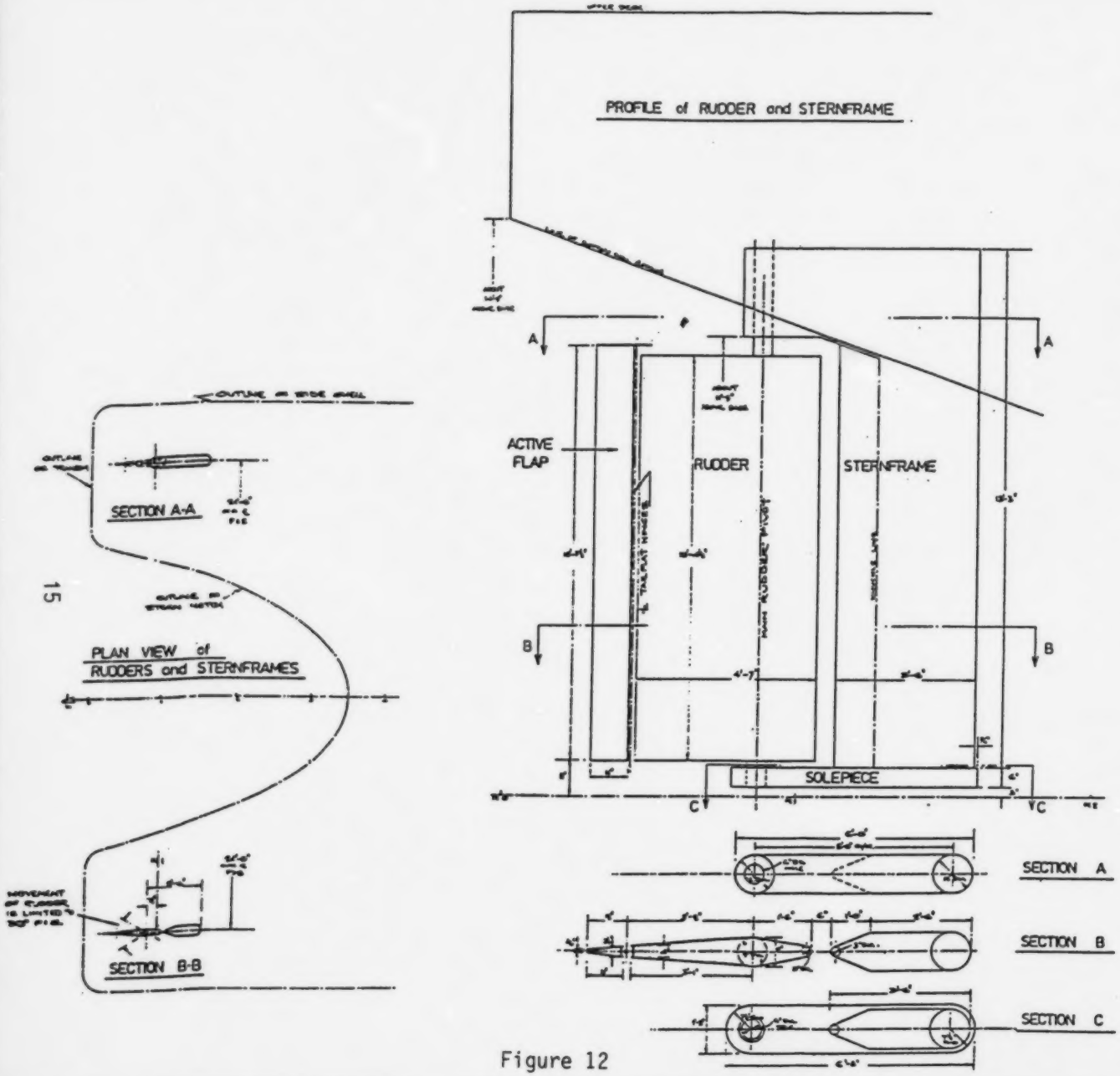

PROFILE of RUDDER and STERNFRAME
ACTIVE FLAP
RUDDER
STERNFRAME
SOLEPIECE
A
B
C
SECTION A-A
PLAN VIEW of RUDDERS and STERNFRAMES
SECTION B-B
SECTION A
SECTION B
SECTION C
BARGE STEERING RUDDERS
TOTAL NAVAL TECHNOLOGICAL ASSOCIATES INC.

Figure 12

2.3.3 Test Arrangements

a. Flowlines. For the flowline tests, the model was taken to the Ocean Engineering Centre at B. C. Research, Vancouver, B. C.

Tufts of black yarn were attached to pins which were tied to the stern rake of the hull so the tufts would be outside the boundary layer. A trip wire was stretched across the flat underside of the hull to stimulate turbulence ahead of the stern rake.

After ballasting to the design 16 foot (scale) draft, the model was attached to the carriage and towed at speeds of 6, 9 and 12 knots past an underwater observation window.

Photographs and video were used to document the flow aligned tufts.

b. Outside Tests

- Barge. The barge model was outfitted for outside tests. Equipment installed included diesel generator, bilge pumps, batteries, battery chargers, speed log, data acquisition system, resistance dynamometer, autopilot and radio.

  The barge model was arranged so that a person could sit in the model to change trim and notch configurations, and operate the data acquisition system.

- Tug. The tug model had twin open propellers, each of which was driven by individual water cooled electric motors with independent proportional power control, by radio control, from full ahead to full astern. The twin rudders were also radio controlled.

  The model was equipped with two heavy duty marine batteries and an automatic bilge pump.

2.3.4 Test Procedures

a. Preliminary procedures. Preliminary towing tests were conducted in April 1987. For these tests the barge model was towed and pushed by the radio controlled tug model. It was found that getting to a suitable test location and conducting the outside tests took too long and was too hazardous.

b. Modified procedure. A modified test procedure was adapted whereby the barge model was towed on a four-conductor, steel reinforced towing cable behind a 9 metre sailboat under diesel power.

At the point of attachment on the sailboat, the towline went through a fairlead attached to a lateral potentiometer which continuously monitored the towline angle and transmitted the signal to the data acquisition system through the conductors in the towline.

On the barge model, the towline was attached to a resistance dynamometer mounted on the bow. A modified autopilot provided continuous heading angle.

Figure 13 shows the modified towing arrangement.

For the integrated tug/barge tests, the radio controlled tug model was entered into the notch. Rubber fenders provided the required constraint around the bow. Stern lines from the port and starboard quarters of the tug to bollards mounted at the aft outboard corners of the barge provided lateral constraint for steerage.

Figure 14 shows the model integrated tug/barge arrangement.

2.4 Tests and Results

2.4.1 Flowline

The videotape of the flowline tests was analyzed frame by frame and the interpolated flowlines superimposed onto copies of the photographs taken through the underwater window. The flow aligned tufts can be clearly seen in photographs 1 - 9 (see Appendix) for each of the notch configurations which were designated large, medium and small.

These photographs were made available to the skeg designers at the completion of the tests in order to prepare the designs for the various skeg types.

2.4.2 Towed Resistance

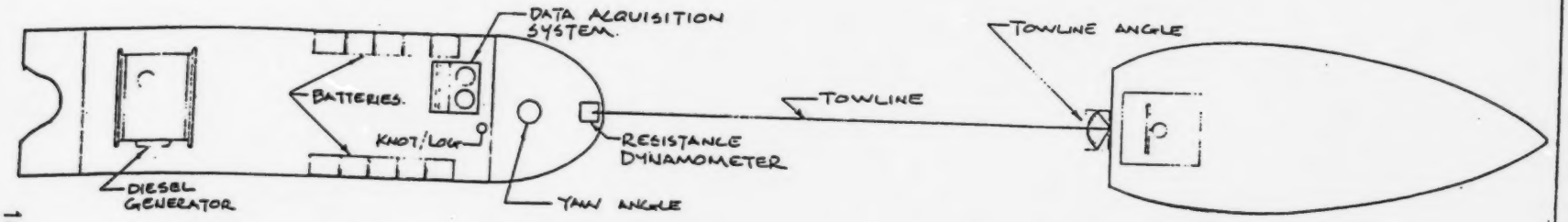
a. General Procedure. For each model configuration evaluated in the towing tests, the barge model was towed at constant speed behind the towing vessel whilst resistance measurements were taken. At the conclusion of the test series all appendages were removed and naked hull resistance determined for each notch configuration.

b. Original Skegs. The test results are shown in Figures 15 and 16 from which it may be seen that resistance increased with speed, notch size, stern trim and flap angle.

The resistance augment vs. speed is presented in Figure 18-2.

c. Hydralift Skegs. Comparative test results are shown in Figures 17 and 18 from which it may be seen that resistance similarly increased with speed, notch size and stern tirm. However, the overall resistance values were lower than for the original skegs.

The resistance augment vs. speed is presented in Figure 18-2 for the original and hydralift skegs from which it may be seen that the hydralift skegs were more efficient.



MODEL BARGE

LWL = 5.39m

SCALE = 1:15

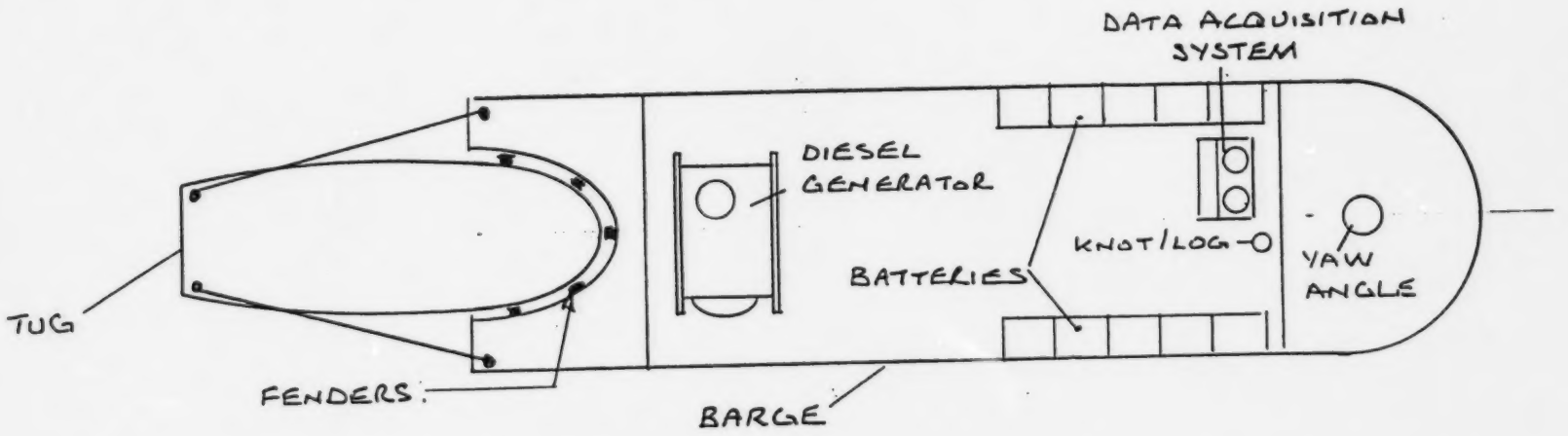
TOWING VESSEL

TEST ARRANGEMENT

TOWLINE LENGTHS :

		TOWLINE/LWL
SHORT :	23.7m	4.40
MEDIUM :	48.1m	8.92
LONG :	70.3m	13.04

Figure 13



TEST ARRANGEMENT.

INTEGRATED TUG / BARGE.

Figure 14

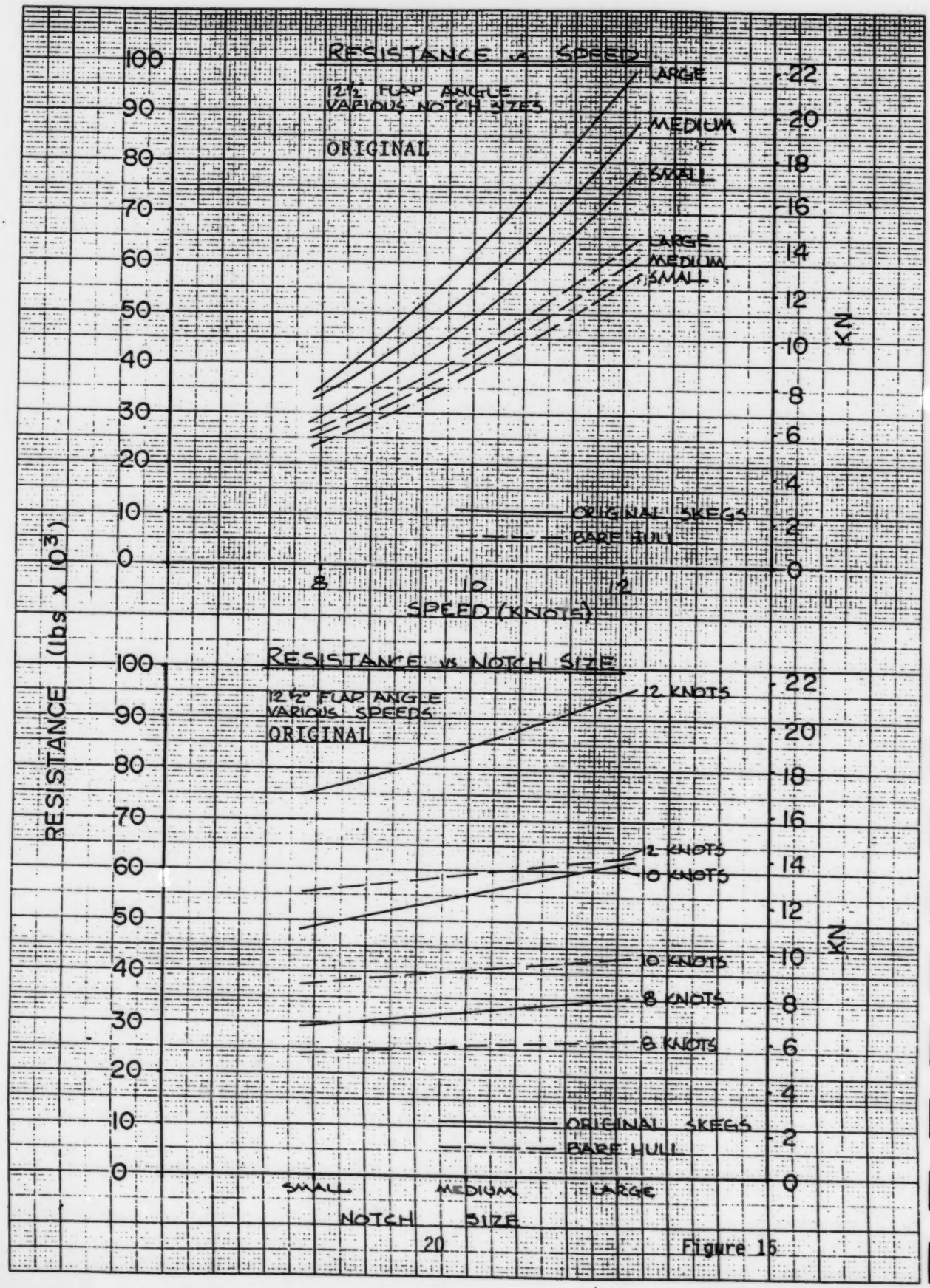


Figure 15

46 1510
K&E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

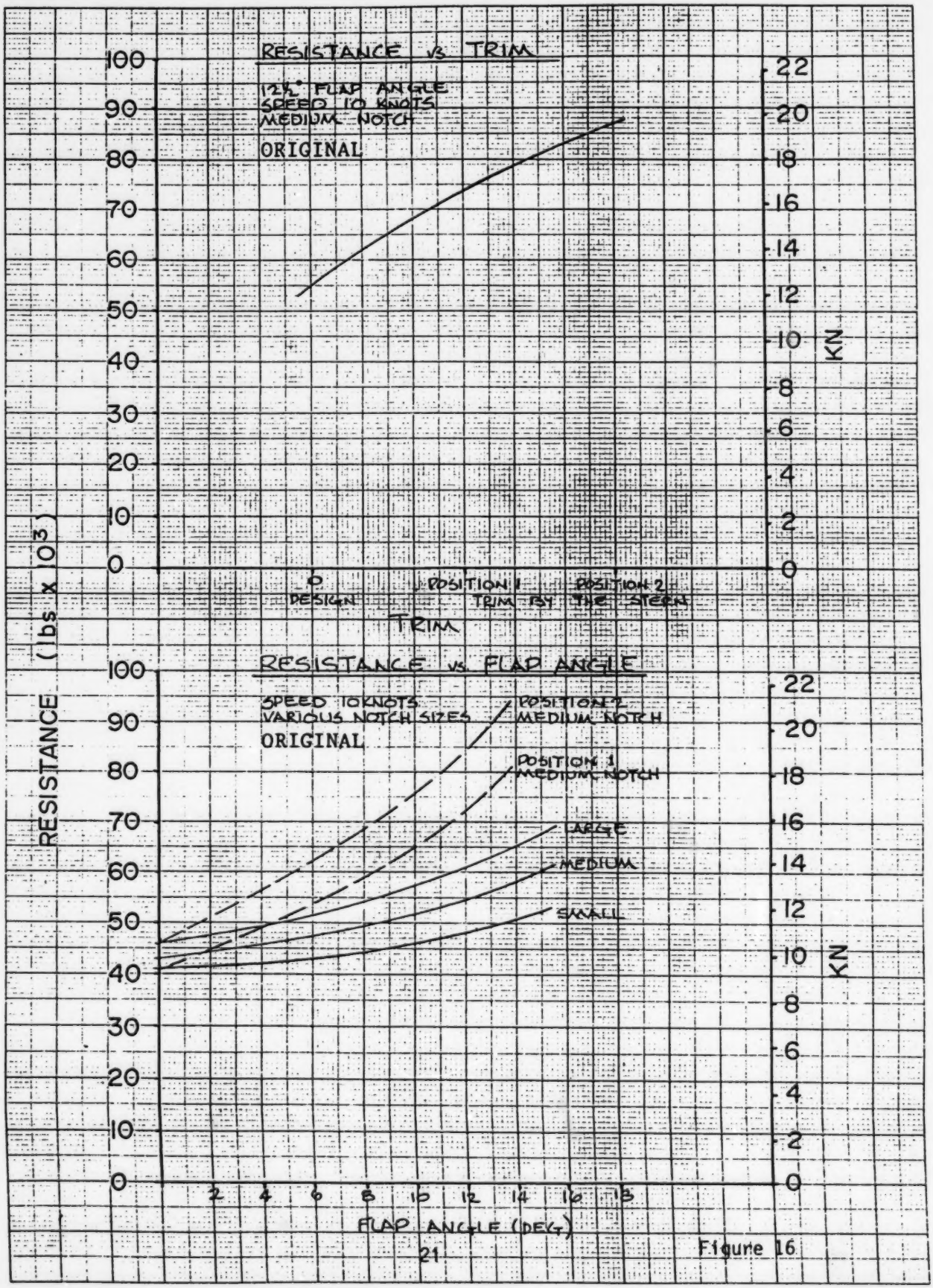


Figure 16

46 1510
10 X 10 TO THE CENTIMETER 13 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

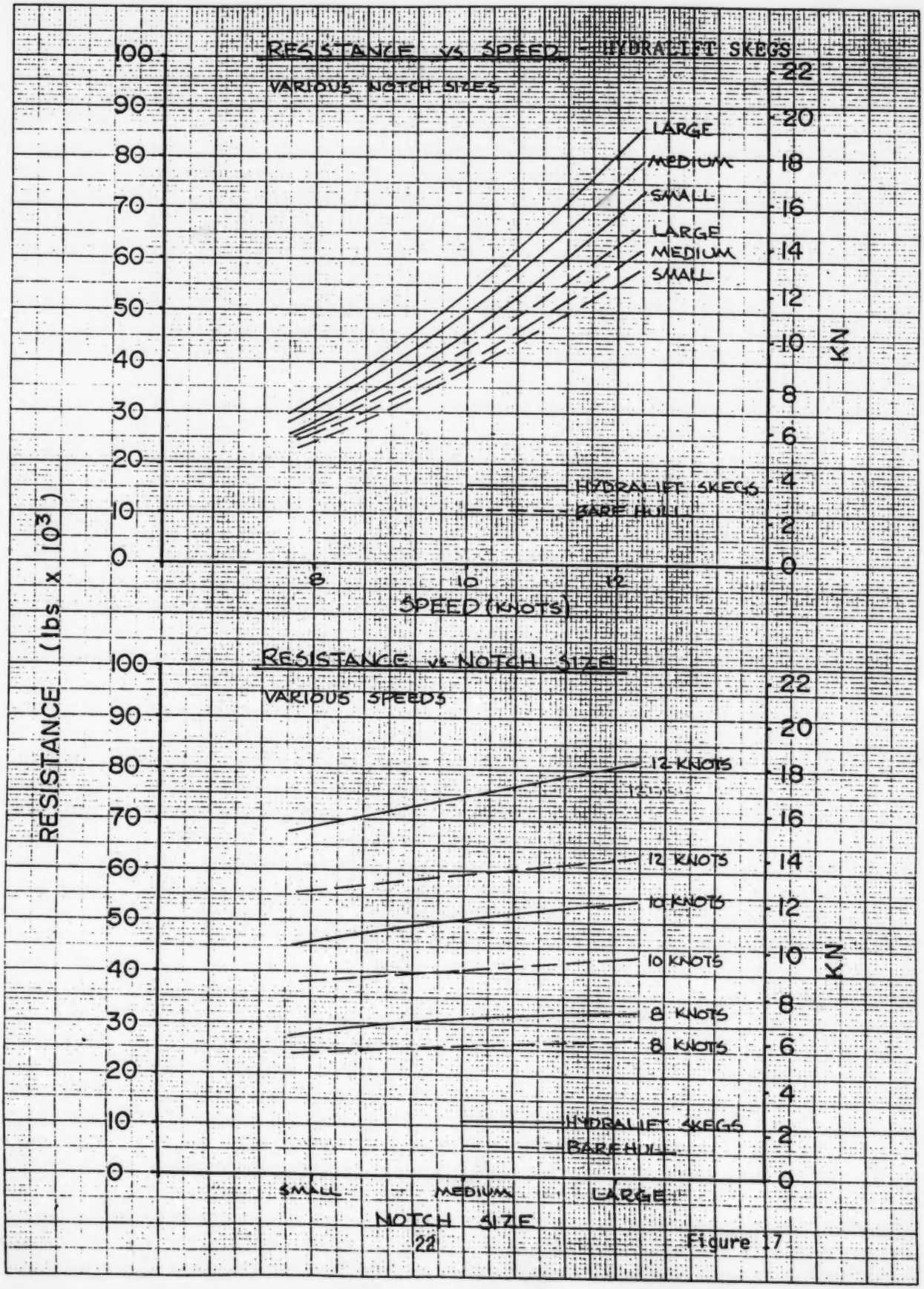


Figure 17

46 1510
K&E 10 X 10 TO THE CENTIMETER 18 X 25 CM.
KEUFFEL & ESSER CO. MADE IN U.S.A.

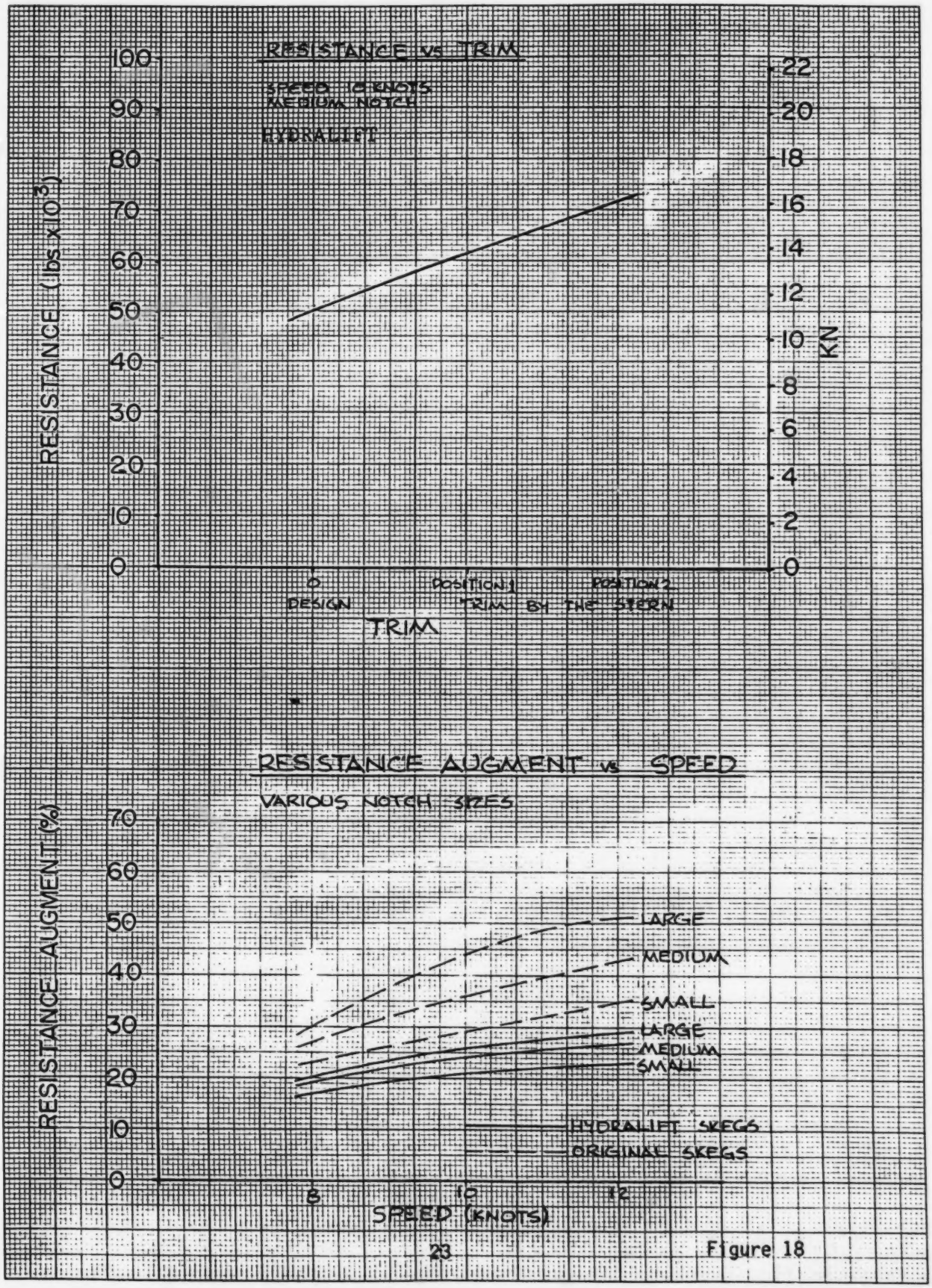

RESISTANCE vs TRIM
SPEED 12 KNOTS
MEDIUM NOTCH
HYDRALIFT
RESISTANCE (lbs x10³)
100
90
80
70
60
50
40
30
20
10
0
22
20
18
16
14
12
10
8
6
4
2
0
KN
0
DESIGN
POSITION 1
TRIM BY THE STERN
POSITION 2
TRIM
RESISTANCE AUGMENT vs SPEED
VARIOUS NOTCH SIZES
RESISTANCE AUGMENT (%)
70
60
50
40
30
20
10
0
LARGE
MEDIUM
SMALL
LARGE
MEDIUM
SMALL
HYDRALIFT SKEGS
ORIGINAL SKEGS
8
10
12
SPEED (KNOTS)

Figure 18

d. T.N.T. Skegs. With these skegs fitted to the barge model, a series of tests was conducted with the rudders set at "fixed" angles up to 35°, and again with the rudders used for steering. Resistance measurements could not be taken as the rudders provided insufficient directional stability for the model to tow straight behind the towing vessel under any of the conditions evaluated.

2.4.3 Towed Directional Stability

a. General Procedure. For each configuration evaluated, the barge model was initially towed at constant speed straight behind the towing vessel whilst resistance measurements were taken and the autopilots on both the towing vessel and the barge model were set on course. The towing vessel was then turned off course by 45° and then allowed to resume course. The towline angle and model heading angle were recorded throughout the manoeuvre. Each test was repeated to port and starboard and the damping factor calculated using the analysis procedure previously defined in section 2.1.

b. Original Skegs. Directional stability was determined to evaluate the effect of flap angle, notch size, stern tirm and towline length.

In order to reduce the number of tests, standardized parameters were used for some evaluations. A flap angle of 12-1/2° was chosen as this appeared to give marginal directional stability during the tests. However, the damping factor was not known at that time. Similarly, 10 knots was chosen as a representative speed to evaluate the effect of trim.

It can be seen from the results presented in Figures 19 - 22 that damping factor increased with flap angle, speed and stern trim.

With a flap angle of 12-1/2°, damping factor decreased with notch size over the tested speed range.

With a flap angle of 12-1/2° at a speed of 10 knots, the medium length towline gave the highest damping factor.

c. Hydralift Skegs. These skegs have no moving parts which reduced the test parameters. Directional stability was determined to evaluate the effect of notch size, stern trim and towline length.

It can be seen from the results presented in Figures 23 - 25 that damping factor increased with speed and stern trim.

Damping factor decreased with notch size over the tested speed range.

At ten knots, damping factor increased with towline length with the small and medium notch. However, with a large notch the medium towline gave the highest damping factor.

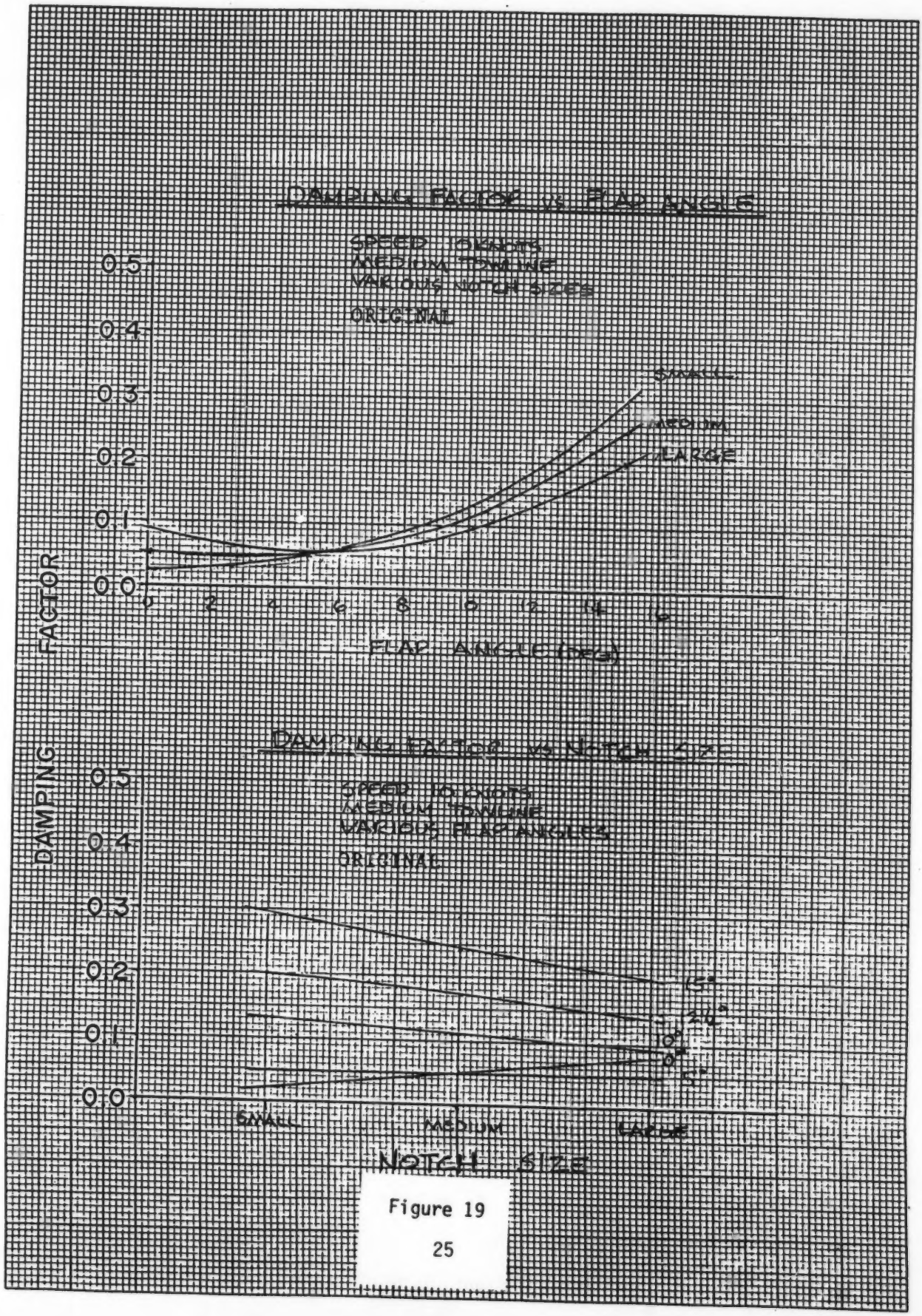

DAMPING FACTOR vs FLAP ANGLE
SPEED 10 KNOTS
MEDIUM TOWLINE
VARIOUS NOTCH SIZES
ORIGINAL
SMALL
MEDIUM
LARGE
DAMPING FACTOR
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
12
14
16
FLAP ANGLE (DEG)
DAMPING FACTOR vs NOTCH SIZE
SPEED 10 KNOTS
MEDIUM TOWLINE
VARIOUS FLAP ANGLES
ORIGINAL
0°
2½°
5°
10°
15°
SMALL
MEDIUM
LARGE
NOTCH SIZE

Figure 19

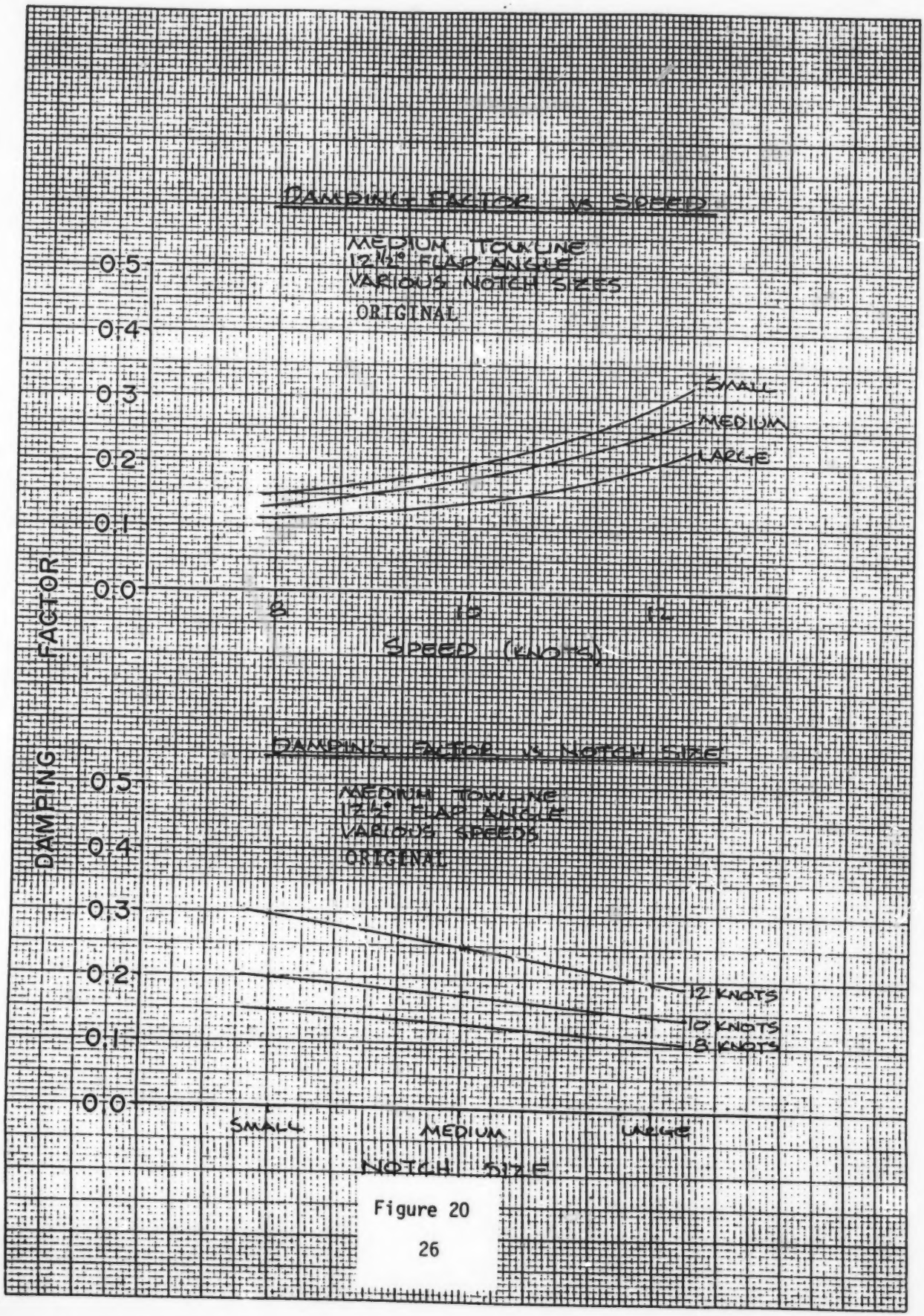


Figure 20

46 1320
K&E 10 X 10 TO ½ INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

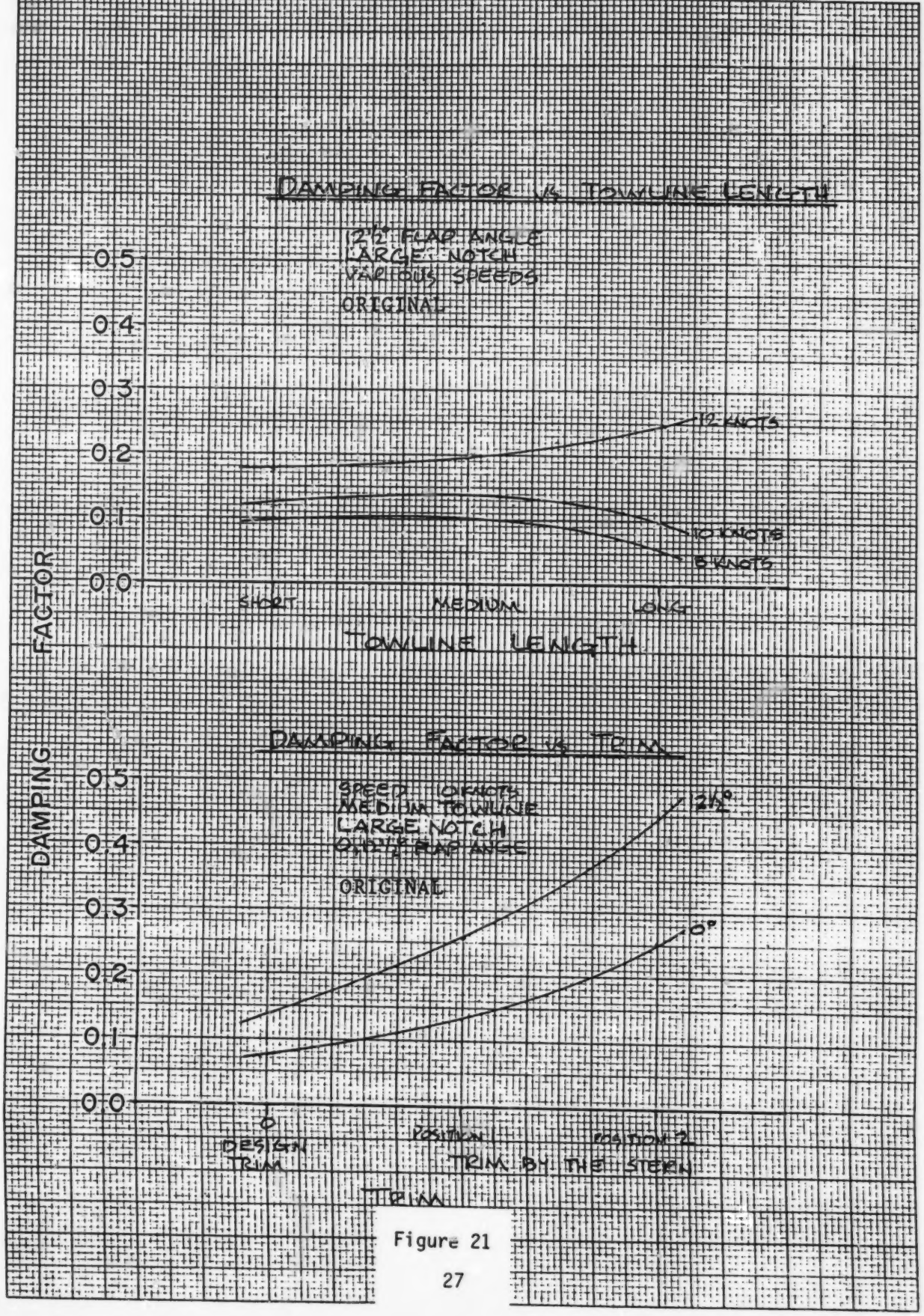

DAMPING FACTOR VS TOWLINE LENGTH
12½° FLAP ANGLE
LARGE NOTCH
VARIOUS SPEEDS
ORIGINAL
DAMPING FACTOR
0.5
0.4
0.3
0.2
0.1
0.0
10 KNOTS
10 KNOTS
8 KNOTS
SHORT
MEDIUM
LONG
TOWLINE LENGTH
DAMPING FACTOR VS TRIM
SPEED 10 KNOTS
MEDIUM TOWLINE
LARGE NOTCH
ORIGINAL
12½°
0°
0
DESIGN TRIM
POSITION 1
POSITION 2
TRIM BY THE STERN
TRIM

Figure 21

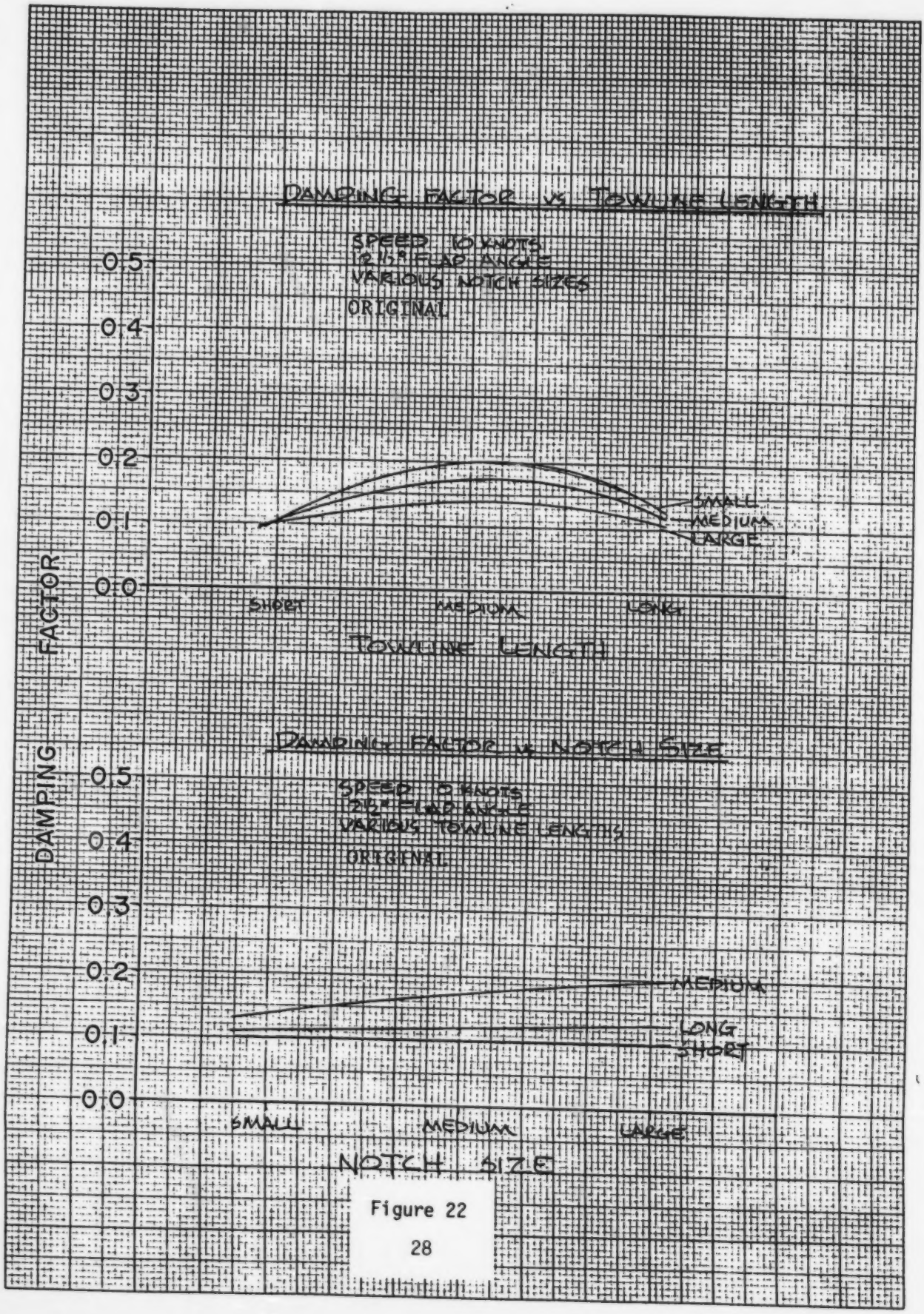


Figure 22

K•E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 1320

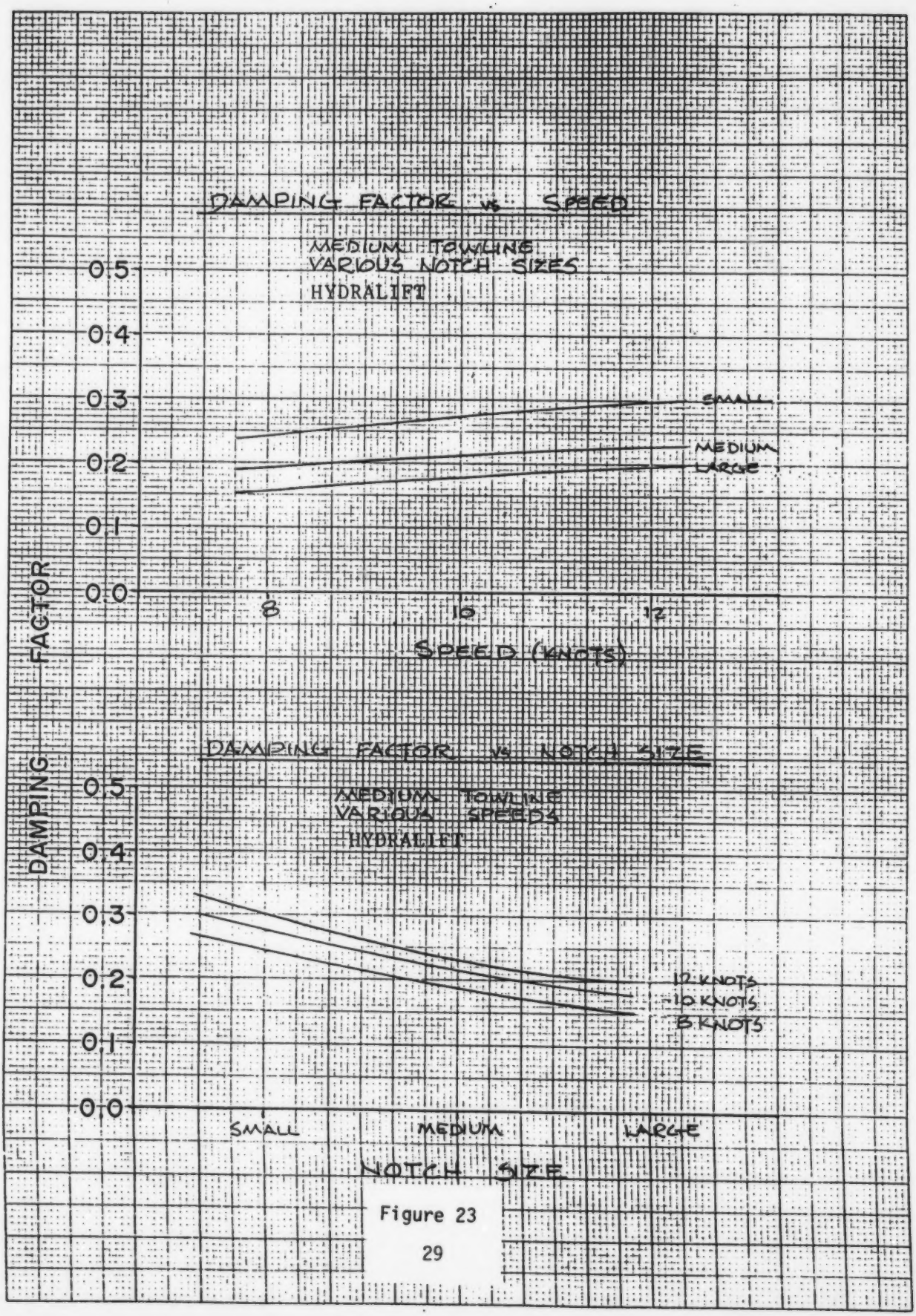


Figure 23

46 1320
KOE 10 X 10 TO THE INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

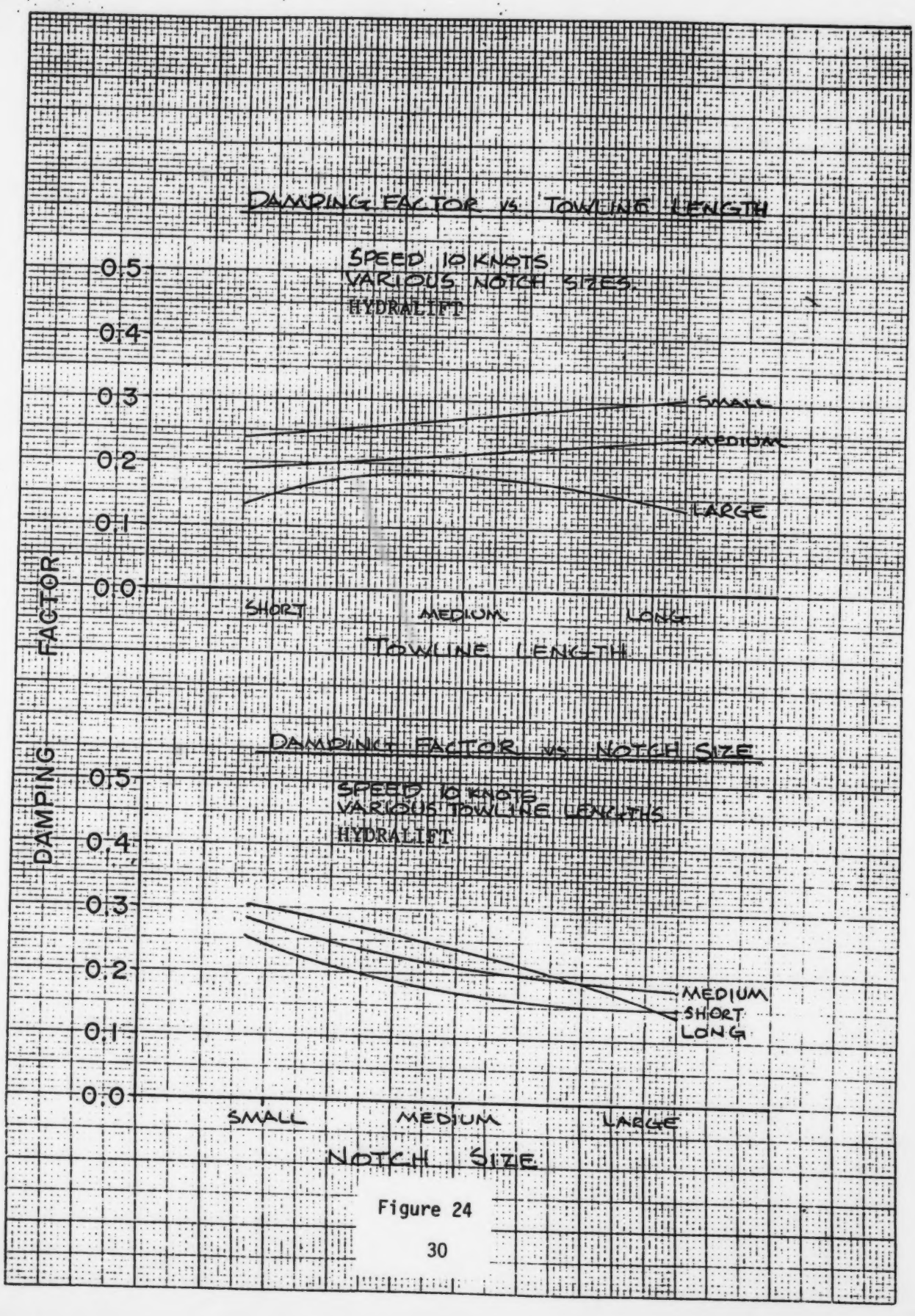


Figure 24

46 1320
K+E 10 X 10 TO ½ INCH 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

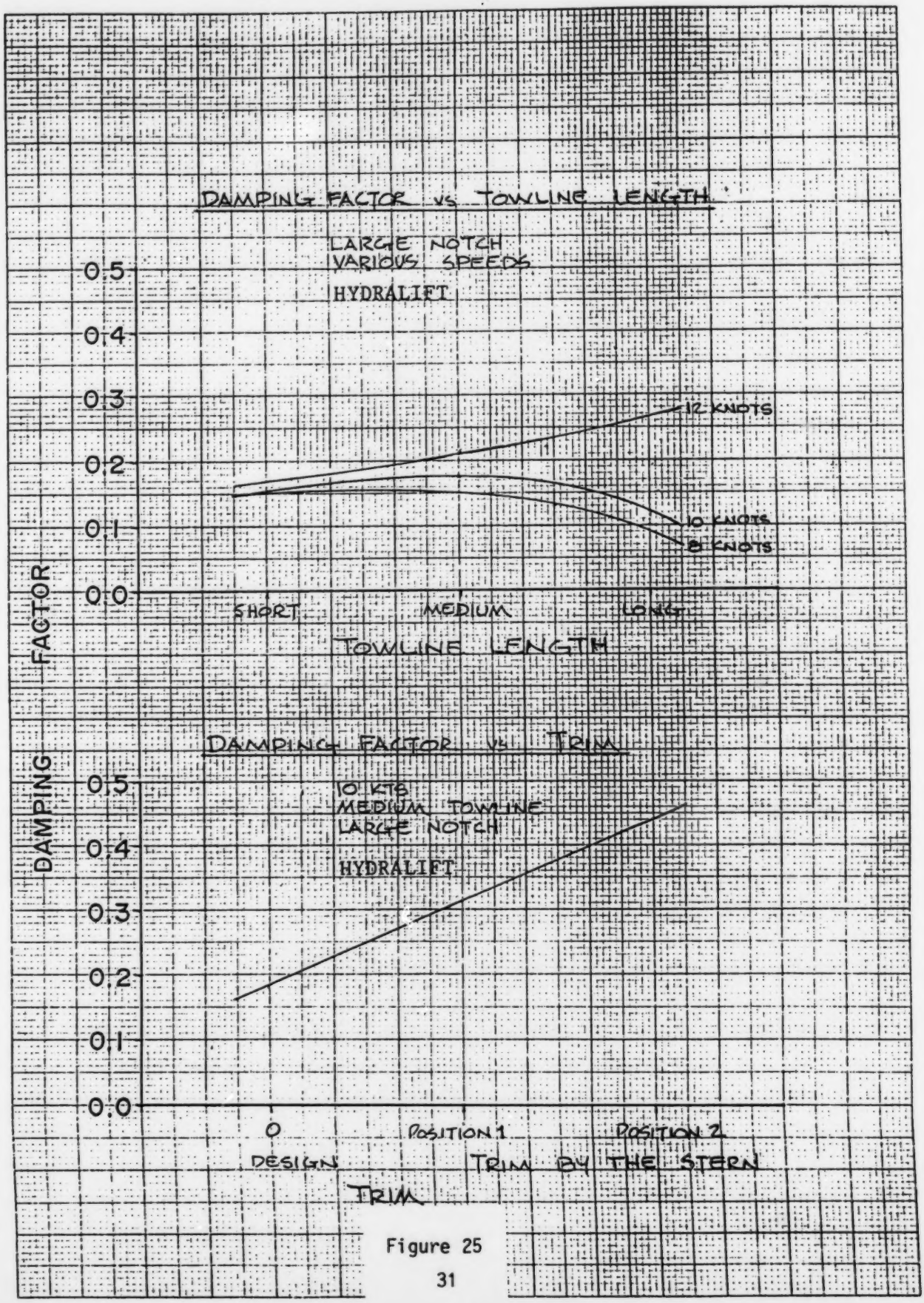

DAMPING FACTOR vs TOWLINE LENGTH
LARGE NOTCH
VARIOUS SPEEDS
HYDRALIFT
0.5
0.4
0.3
0.2
0.1
0.0
DAMPING FACTOR
12 KNOTS
10 KNOTS
8 KNOTS
SHORT
MEDIUM
LONG
TOWLINE LENGTH
DAMPING FACTOR vs TRIM
10 KTS
MEDIUM TOWLINE
LARGE NOTCH
HYDRALIFT
0.5
0.4
0.3
0.2
0.1
0.0
DAMPING FACTOR
0
DESIGN
POSITION 1
POSITION 2
TRIM BY THE STERN
TRIM

Figure 25

d. T.N.T. Skegs. With these skegs fitted to the barge model, a series of tests were conducted with the rudders set at "fixed" angles up to 35° and with them used for steering. The T.N.T. skegs provided insufficient directional stability to the barge with any of the configurations evaluated at level trim. Each successive yaw and towline angle amplitude became increasingly larger until limited by towline length. For all level trim conditions the damping factor was negative.

With stern trim it was just possible to maintain positive directional control using the active rudders but not with fixed rudder angles to 35°. Quantitative data were not acquired for these tests as it was not possible to maintain a controlled test as with previous skeg configurations.

2.4.4 Integrated Tug/Barge

a. General Procedure. At the conclusion of the towing tests, a series of tests was conducted to evaluate the manoeuvrability of the integrated tug/barge (IT/B) configuration. As the original skegs had adjustable flaps they were allowed to trail freely and find their own position. This angle was approximately +2°. The Hydralift skegs were fixed.

A zig-zag manoeuvre was conducted at 10 knots. For this the rudders were initially turned 30° to port. When the heading angle of the IT/B equalled the rudder angle, the rudders were turned to 30° to starboard. When the heading angle of the IT/B equalled the rudder angle, the rudders were turned to 30° to port. This sequence was repeated for several oscillations.

Turning circles at fixed rudder angles to port and starboard were also conducted to evaluate controllability.

b. Original Skegs. With the skegs allowd to trail freely, the IT/B was manoeuvrable and controllable both at level and stern trim. With stern trim the IT/B became more directionally stable and the overshoot angle decreased.

With flap angles set at +12-1/2°, the manoeuvres were repeated but showed no measurable difference in manoeuvrabilty or controllability.

Although the resistance of the IT/B in the pushing mode could not be measured, it may be estimated by assuming that it was equivalent to the towed resistance with flaps trailing at +2°.

Data from Figure 16-2 at 10 Knots	
Notch Size	Resistance (Knots)
Small	9.3
Medium	9.9
Large	10.6

c. Hydralift Skegs. With these skegs, the IT/B was slightly less manoeuvrable but exhibited improved directional stability over the original skegs. Overshoot decreased but reach increased marginally.

Although the IT/B was still manoeuvrable and controllable, the above tendencies became more evident with stern tirm.

The resistance in the pushing mode may be estimated if the assumption is made that it is equivalent to the towed resistance.

Data from Figure 17-1 at 10 Knots		
Notch Size	Resistance (Knots)	Increase from Original (%)
Small	10.3	10
Medium	11.1	12
Large	12.1	14

The increased resistance from the original skegs was due to the Hydralift skegs having fixed angles of attack, compared to the original skegs being capable of trailing.

d. T.N.T. Skegs. Pushing tests with the IT/B configuration were not conducted.

2.5 Video

A 1/2" VHS vido was taped to document the test procedures. Also to demonstrate the manoeuvrability and controllability of the IT/B configuration.

The outside test sequences were taped in real time. To approximate the motions of a full scale configuration, the video tape should be slowed down by a factor of 3.87.

3.0 CONCLUSIONS

3.1 General

The presence of a stern notch in a barge has a negative influence upon the directional stability and the resistance of the vessel when being towed. From observations of both the model and a full size vessel under tow, the notch creates a large low pressure area which appears to cause unstable flow vortices to develop. These vortices will "shed" from the notch, alternatively from side to side of the barge, thus totally disrupting the regular flow regime in the vicinity of the skegs and causing the barge to yaw. This yawing, if in phase with and in the same direction as the natural circular frequency of the barge/skeg configuration, will develop into a large amplitude yaw oscillation.

There are forms of skegs which, if carefully positioned with respect to the flowlines, can be matched to a barge with a stern notch which will provide the degree of directional stability required if the barge must be towed as a routine part of its service.

There is, however, a minimum transverse area of skeg which is required to enable a barge to be controlled in this fashion.

3.2 Damping Factor

From a large library of data on similar barge course stability testing, and from correlation of both qualitative and quantitative data from this test program, we conclude that a damping factor of 0.15 is required to produce marginal directional stability. To ensure adequate towed directional stability, a damping factor of 0.20 is required.

This is consistent with the behaviour of the majority of barges operating on the West Coast of Canada.

3.3 Flowlines

The presence of a stern notch has a definite impact on the flowlines at the stern of the barge, and the larger the notch, the greater the impact.

The naked hull flowlines with a notched stern were observed to be more curved and to have a greater inflow angle at the skeg leading edge position than with a conventional stern rake form.

With the longest notch, naked hull flowlines were more curved at the after end, particularly at lower speeds than for the smaller notch sizes.

3.4 Resistance

3.4.1 Towed

With a damping factor of 0.2 (by our definition the requisite value to provide adequate directional stability), the towed resistance of the adjustable flap skegs was 15% higher than with the Hydralift skegs.

3.4.2 Pushed

In the pushed mode, the "integrated tug-barge" configuration was estimated to have 10 - 14% more resistance with the Hydralift skegs than with the adjustable flap skegs in the "push" position. This reflects the fact that these skegs, when in this mode, offer little directional stability, and are totally aligned with the flow.

3.5 Effects of Various Skeg Types

3.5.1 Adjustable Flap Skegs

The following effects were noticed in the testing of this skeg type:

- Towed directional stability increases with increased flap angle, with speed.
- Towed directional stability decreases with increases in notch size.
- The effects of towline length were varied and inconsistent.
- These skegs, in the original design configuration, with the barge at level trim, produce only marginal directional stability at 8 knots with the small notch. With larger notches, the barge was directionally unstable. At 12 knots, however, the design configuration produced adequate directional stability with all variations in notch size.
- Directional stability increases with increasing stern tirm, as does barge resistance.

3.5.2 Hydralift Skegs

These skegs, fixed in position, produced adequate towed directional stability (damping factor 0.2 or greater) with all three notch sizes over the speed range of 8 - 12 knots.

3.5.3 T.N.T. Skegs

The design arrangement of these "steering flap" skegs, as proposed by T.N.T. for this project, could not be made to provide sufficient directional stability for the barge in any of the configurations tested. Thus a quantitative assessment of the resistance augment or damping factor could not be made.

It is the opinion of the author that this skeg could be made to work, in similar fashion to the adjustable flap type, if greater control surface area were provided.

3.6 Test Methodology

The benefit of conducting this type of test in calm outside waters was reinforced in this program. Since the yaw frequency of many barges is a period of approximately 600 - 700 seconds, it is very difficult to properly assess the yaw characteristics of such vessels within the constraints of an experimental model basin.

This methodology also permits the use of larger scale models, improving the accuracy of the experiments. There are, however, influences of wind, tide and curious onlookers which can detrimentally influence the test procedure.

3.7 Notch Effects

The generation of vortices within the notch, and the shedding of these vortices, are phenomena of the notch geometry, and will occur in this type of stern geometry regardless of skeg configuration. The critical aspect is to avoid a vortex-shedding frequency which is in phase with the natural circular frequency of the barge/skeg configuration.

This can only be determined by the type of long-duration testing as performed during this program.

4. RECOMMENDATIONS

The test program conducted provided useful insights into the towed behaviour of barges equipped with stern notches.

The geometry of the notch, and associated flow instability, are the source of previously observed directional stability problems.

This program identifies the problems associated with using push-barges of conventional notched form, however, the obvious challenge would be to investigate stern forms which could accommodate the required tug-notch for a push-tow configuration, but with minimized resistance and, hopefully, improved directional stability.

There are aspects of the test procedure where the results lead one to suspect the experimental accuracy of the testing program, namely in the effects of varying towline length. Due to the inordinate time required for slow speed tests of this nature, it is difficult to obtain a large number of data points for each variable tested. The towline length test results should be viewed with some skepticism until further testing of this phenomenon alone can be investigated in more detail.

APPENDIX - PHOTOGRAPHS OF FLOWLINE TESTS

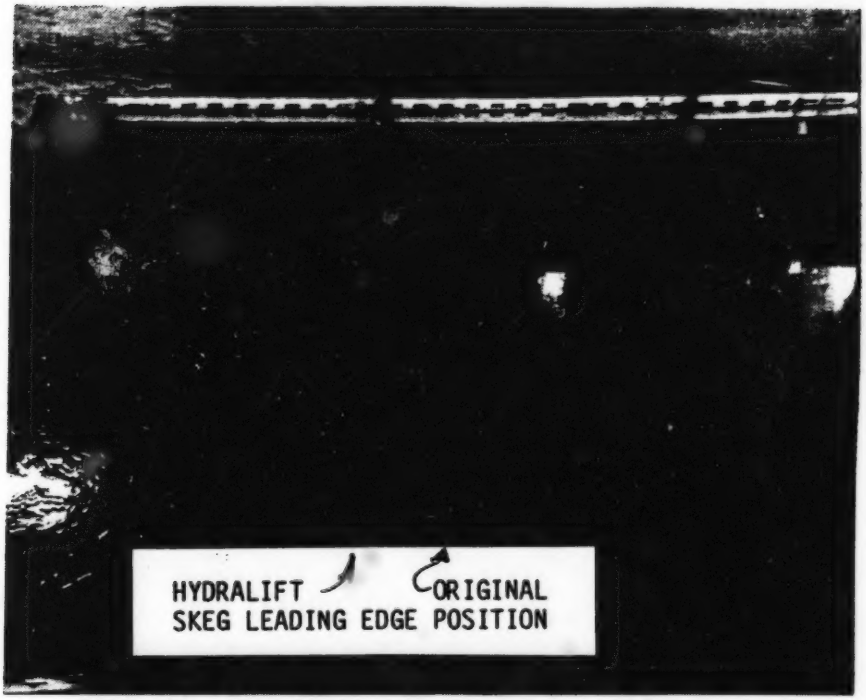


Photo #1 - Flowlines - Large Notch - Speed 6 Knots

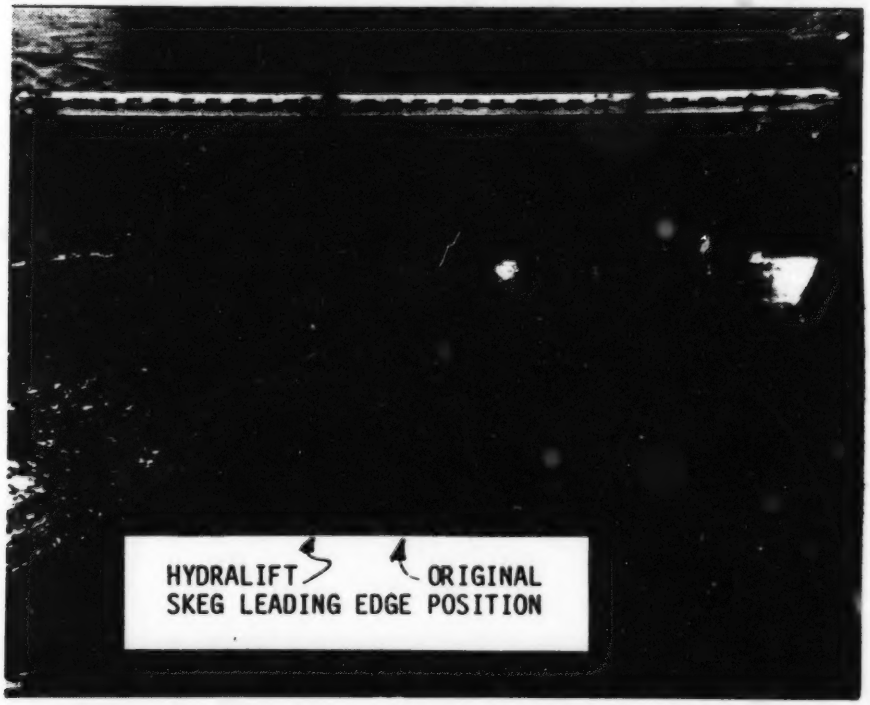


Photo #2 - Flowlines - Large Notch - Speed 9 Knots

APPENDIX - PHOTOGRAPHS OF FLOWLINE TESTS

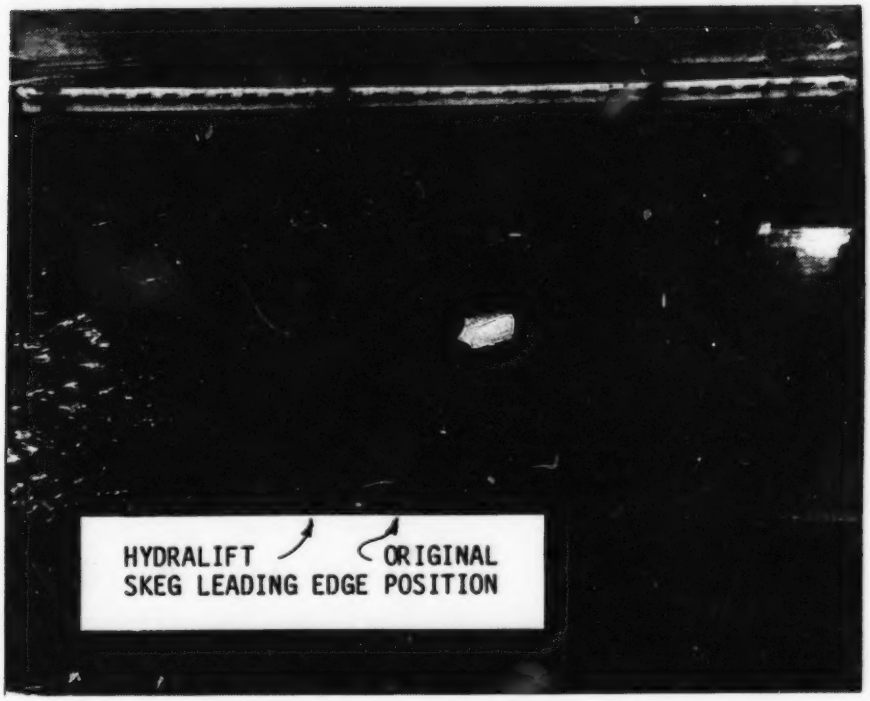


Photo #3 - Flowlines - Large Notch - Speed 12 Knots

APPENDIX - PHOTOGRAPHS OF FLOWLINE TESTS

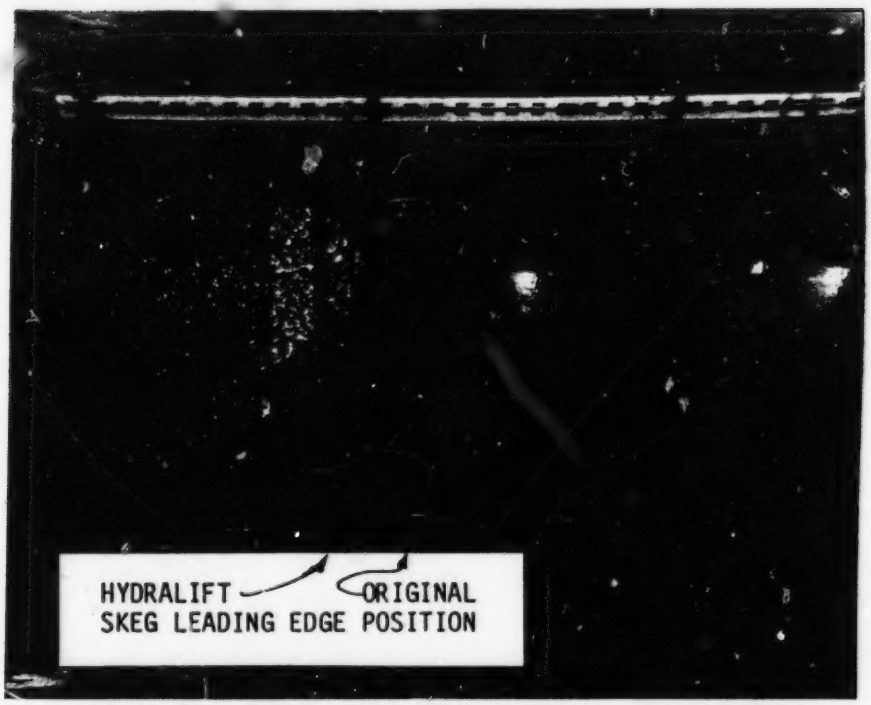


Photo #4 - Flowlines - Medium Notch - Speed 6 Knots

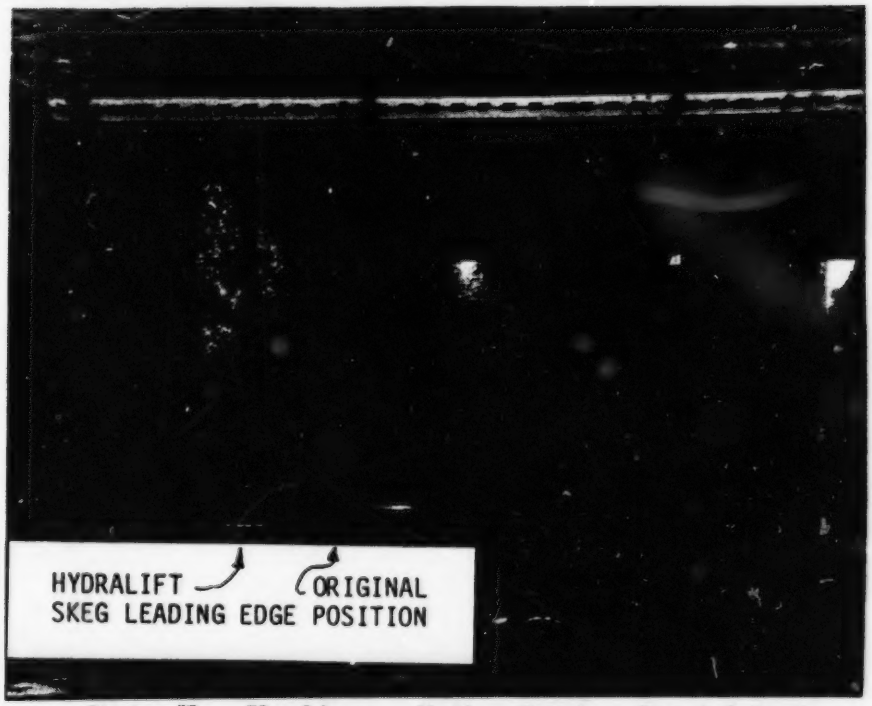


Photo #5 - Flowlines - Medium Notch - Speed 9 Knots

APPENDIX - PHOTOGRAPHS OF FLOWLINE TESTS

Photo #6 - Flowlines - Medium Notch - Speed 12 Knots

APPENDIX - PHOTOGRAPHS OF FLOWLINE TESTS

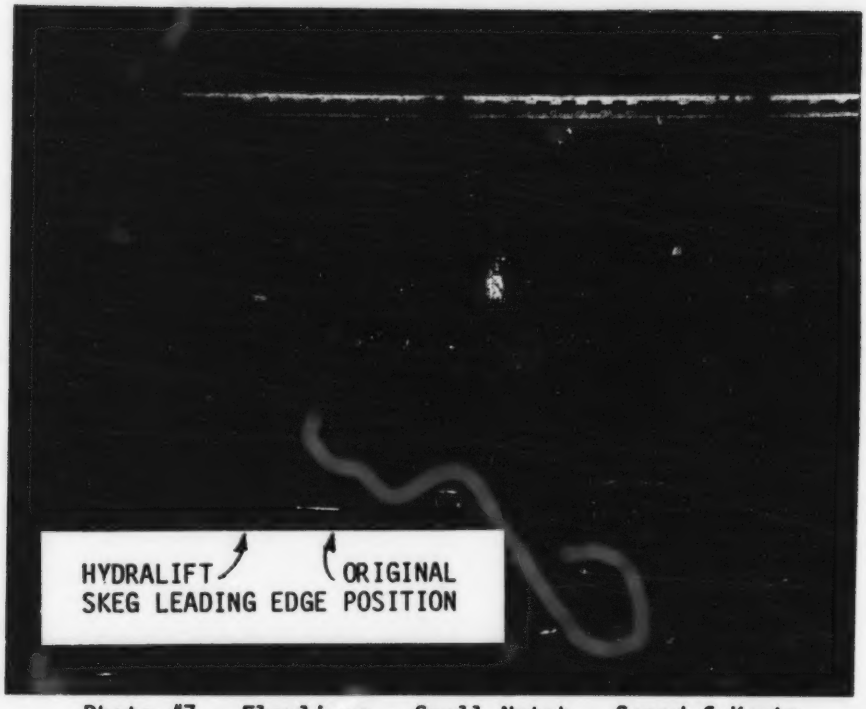


Photo #7 - Flowlines - Small Notch - Speed 6 Knots

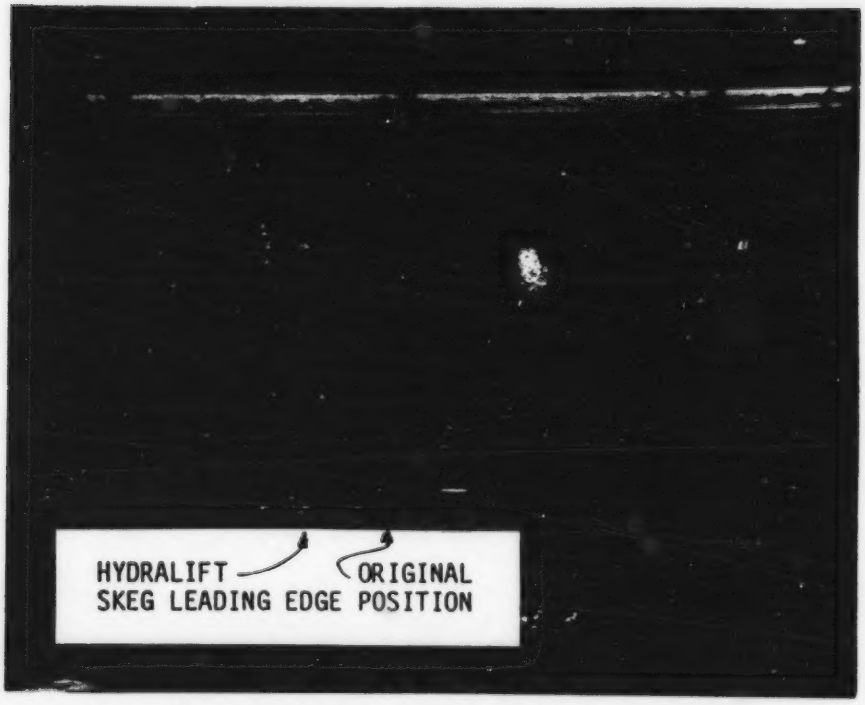


Photo #8 - Flowlines - Small Notch - Speed 9 Knots

APPENDIX - PHOTOGRAPHS OF FLOWLINE TESTS

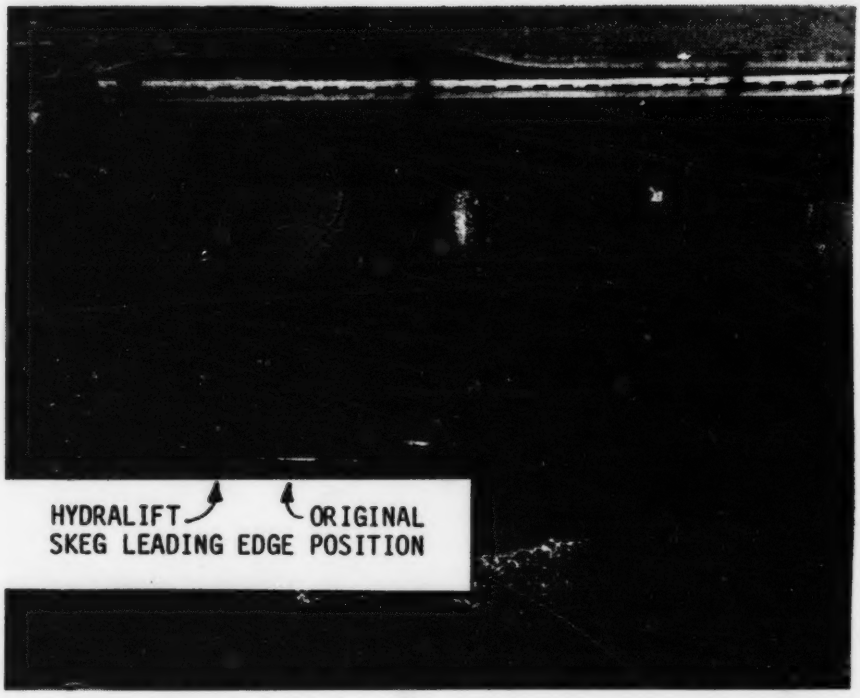


Photo #9 - Flowlines - Small Notch - Speed 12 Knots